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**XXIX.** *On the Determination of Chemical Affinity in terms of Electromotive Force.—Part I.* By C. R. ALDER WRIGHT, *D.Sc. London, Lecturer on Chemistry and Physics in St. Mary's Hospital Medical School.*

1. BETWEEN the years 1841 and 1846 Joule made a series of experiments on the development of heat during electrolysis, which led him to the conclusions :—that when a current is passed through a fluid conductor, heat is developed in accordance with the same law as that which he found to obtain with a solid metallic wire, viz. that the heat produced in a given time is proportionate to the square of the current and to the resistance of the conductor—usually known as Joule's law ; that if electrolysis is produced, the actual heat developed in the electrolyte is less than that deducible from this law by a quantity precisely equal to the amount that would be given out in re-forming from its products of decomposition the compound decomposed ; and consequently that it is possible to determine the “heat of formation” of a compound by the inverse method of determining the heat absorbed during its electrolysis. The actual results thus obtained, as regards the “heat of formation” of copper sulphate, zinc sulphate, and water, were communicated to the French Academy in 1846, but were not published in detail until 1852 (*Phil. Mag.*)

[4] vol. iii. p. 481). Some few months before they appeared, Dr. Thomas Woods published (*ibid.* vol. ii. p. 268) the results of experiments showing that in the decomposition of water by electrolysis a quantity of heat is taken up approximately equal to that evolved by the recombination of the hydrogen and oxygen evolved.

2. Joule's method of operating is described by him in the following words:—"I take a glass vessel filled with the solution of an electrolyte and properly furnished with electrodes; I place the electrolytic cell in the voltaic circuit for a given length of time, and carefully observe the quantity of decomposition and the heat evolved. By the law of Ohm I then ascertain the resistance of a wire capable of obstructing the current equally with the electrolytic cell. Then by the law we have proved [*i. e.* 'Joule's law'] I determine the quantity of heat which would have been evolved had a wire of such resistance been placed in the current instead of the electrolytic cell: this theoretical quantity, being compared with the heat actually evolved in the electrolytic cell, is always found to exceed the latter considerably. The difference between the results evidently gives the quantity of heat absorbed during the electrolysis, and is therefore equivalent to the heat which is due to the reverse chemical combination by combustion or other means" (*loc. cit.* pp. 493, 494).

Put into symbols this may be thus expressed:—Let  $h_1$  be the heat actually developed in the electrolyte by a current  $C_1$  in a given time  $t$  during which  $w_1$  grammes of electrolyte are decomposed. Let  $h_2$  be the heat that would be developed in a wire of the same resistance (*i. e.* capable of equally "obstructing the current") in the same time  $t$  by the same current  $C_1$ . Let  $h_3$  be the heat actually developed in another wire by a different current  $C_2$  in the same time  $t$ ; and let the resistance of the electrolytic cell be  $a$  times the resistance of this second wire. Then, by Joule's law,

$$\frac{h_2}{h_3} = \frac{C_1^2}{C_2^2} a,$$

whence the heat absorbed in decomposing  $w$  grammes of electrolyte is

$$h_2 - h_1 \text{ or } = h_3 \frac{C_1^2}{C_2^2} a - h_1,$$

and the heat absorbed in decomposing 1 gramme of electrolyte is

$$\frac{h_3 \frac{C_1^2}{C_2^2} a - h_1}{w}.$$

In this way Joule obtained in three sets of observations the following mean values for the heat absorbed in the decomposition of a gramme-equivalent of water:—

34101	
34212	
32356	
<b>Average . . .</b>	<b>33557</b>

the numbers found by direct determination of the heat of combustion of hydrogen in oxygen being close to 34100 gramme-degrees, according to the most trustworthy experiments (*vide* § 31).

3. Joule further applied this principle to the electrolysis of zinc and copper sulphates, and found that the heat actually developed in the electrolytic cell was in each case less than that which would be developed in a wire “obstructing the current” equally with the cell by a quantity sensibly equal to the heat that would be generated by the oxidation of the metal liberated during the electrolysis by the oxygen simultaneously set free, together with that produced by the solution in the dilute sulphuric acid also formed of the metallic oxide thus produced. That this should be so is an evident deduction from the principle of conservation of energy; for if the total work that could be done in the passage of a current  $C$  through a resistance  $R$  in a time  $t$  be expressed by the formula  $C^2Rt$  (Joule’s law), and some of that work be performed not as heat but in undoing chemical combination, it results that the amount of work actually done as sensible heat must be just so much less than  $C^2Rt$  as corresponds to the chemical work performed.

4. The experiments of Woods were of a far less accurate kind than those of Joule, but were based on much the same principles. A current being passed through an electrolytic cell for a given time, the heat developed was roughly measured and the amount of decomposition; a wire was then substituted for this electrolytic cell of such resistance that the current

passing was the same as before (the electromotor remaining the same). The heat developed in this wire being determined, was found to exceed that produced in the electrolytic cell in the same time by a quantity sensibly equal to that which would be generated by the recombination of the products of electrolysis.

The formula just deduced for Joule's method of experimenting then becomes

$$\frac{h_3 - h_1}{w},$$

for  $C_1 = C_2$  and  $a = 1$ .

5. In 1865 Joule's results were confirmed by Raoult (*Ann. de Chim. et de Phys.* 4th series, ii. p. 317, and iv. p. 392) by a method which will be discussed later on (§ 23). The amount of heat absorbed per gramme-equivalent of water decomposed was found by Raoult to be 34028, or sensibly the same as that deduced by direct combustion; whilst similar results were obtained with copper sulphate. In 1869 Kiechl published experiments (*Wien. Akad. Ber.* lx. [2] 121) in principle the same as Joule's, but differing considerably in the details, notably in that the wire was made into a rheostat, so that its resistance could be regulated throughout the observations. As a mean of nine accordant experiments, 33653 was found to be the heat absorbed per gramme-equivalent of water decomposed. Shortly before this, Favre demonstrated in a very simple way (*Comptes Rendus*, lxvi. p. 252; *Pogg. Ann.* cxxxv. p. 300) that as much heat is absorbed during the decomposition of an electrolyte as is produced by the recombination of the products of decomposition. A small battery was enclosed in a calorimeter, and the heat produced by the solution of a given quantity of zinc determined, the current produced being made to circulate through a coil of wire also contained in the calorimeter; so that the total heat generated was determined. A voltmeter was then substituted for the coil of wire, when the quantity of heat was found to be lessened by an amount equal to 34,204 gramme-degrees per gramme-equivalent of zinc dissolved, *i. e.* of water decomposed. Similarly when copper sulphate was decomposed instead of water, the heat-evolution was lessened by an amount sensibly equal to the heat evolved in the synthesis of the salt.

6. In 1851 Sir William Thomson carried the ideas suggested by the experiments of Joule and others a considerable way further. In a remarkable paper on the mechanical theory of electrolysis (Phil. Mag. 1851, vol. ii. p. 429), he demonstrated that the force of chemical affinity is expressible in terms of electromotive force, and calculated, from data largely furnished by Joule, that the work done in decomposing water corresponds to an E.M.F. of  $3,305,400$  foot-grain-second electromagnetic units (equal to  $1.415 \times 10^8$  C.G.S. units, or  $1.415$  volt), that representing the sum of the chemical actions in a Daniell cell corresponding to  $2,507,100$  (equal to  $1.074 \times 10^8$  C.G.S. units); so that the "affinity" between oxygen and hydrogen in water is  $\frac{1.415}{1.074} = 1.318$  times as strong as the sum of the affinities exerted in the chemical changes going on in a Daniell cell. Similar calculations, based on more recent determinations of the values involved, lead to somewhat higher numbers, approximating to  $1.502 \times 10^8$  C.G.S. units for water and  $1.154 \times 10^8$  for the Daniell cell (*vide* § 16), giving the ratio  $\frac{1.502}{1.154} = 1.302$ .

7. The general proposition that the force of chemical affinity is expressible in terms of E.M.F. may be simply demonstrated as follows:—Let the strength of chemical combination, or the chemical work done by the force of chemical affinity, be defined as the absolute amount of work spent or gained in the synthesis from its constituents of a given weight (say 1 gramme) of the compound considered. This work may be expressed in terms of heat, and is ordinarily measured as such: thus in the synthesis of a gramme of water from gaseous oxygen and hydrogen at the ordinary pressure and temperature, an amount of work is done representing an evolution of a quantity of heat amounting, according to the most accurate determinations, to close upon 3800 gramme-degrees (§ 31); whence, taking the mechanical equivalent of heat as 42 megalergs per gramme-degree\*, the work done in this synthesis is close to 16 erg-tens =  $16 \times 10^{10}$  C.G.S. units.

\* The values obtained by Joule by friction of water lie somewhat below this figure (near to  $41.5 \times 10^6$ ): whilst that deduced by him from the development of heat by electric currents in a wire of known resistance

The experiments of Faraday first demonstrated the two following laws, which have since been fully confirmed by many other experimenters:—

I. When a compound is electrolyzed, the weight of substance decomposed is proportionate to the quantity of electricity passing. [A low degree of conductivity is supposed by some experimenters to be possessed by electrolytes, of such a nature that very feeble currents can be passed through them without causing any chemical decomposition ; this, however, even if admitted to be the case, would not appreciably interfere with the correctness of the foregoing proposition.]

II. When a current is passed for a given time successively through several compounds so as to electrolyze them all, it decomposes quantities of them in the ratio of simple functions of their "molecular weights," evolving the products of decomposition, when elementary, in the ratio of simple functions of their combining numbers or "atomic weights." The quantities of compounds decomposed and of elements evolved by a current which evolves 1 part of hydrogen from water under these circumstances are called their "equivalent values," or, more briefly, their *equivalents*, in reference to the particular compounds decomposed.

Law I. may be thus expressed :—Let  $n$  be the number of grammes of compound decomposed, and  $q$  the quantity of electricity passing ; then

$$n \propto q.$$

Law II. states that, if  $a$  be the "equivalent" of a given compound,

$$n \propto a.$$

Hence

$$n \propto aq;$$

and consequently

$$n = aq \times \chi,$$

where  $\chi$  is a multiplier independent of the quantity of electricity passing, and of the value of the "equivalent" of the compound.

lies somewhat above it ( $42 \cdot 10 \times 10^6$ ). Numbers lying somewhat above  $42 \times 10^6$  have been obtained by Hirn, Viole, and Regnault (*vide* §§ 33 & 34).

When  $n=a$ ,  $\chi=\frac{1}{q}$ ; that is,  $\chi$  is the reciprocal of the quantity of electricity requisite to decompose a gramme-equivalent of the electrolyte employed. For convenience of reference,  $\chi$  may be termed the *electrochemical constant*.

8. The term "electrochemical equivalent of a substance" is employed to mean the quantity of substance decomposed by a unit quantity of electricity, *i. e.* the value of  $\frac{n}{q}$  (which =  $a\chi$ ); and the term "electrochemical equivalent of an element," in reference to such a compound, is used to indicate the quantity of that element evolved during electrolysis of that compound during the passage of a unit of electricity. If  $b$  be the equivalent of the element in reference to the compound employed, the equivalent of the compound being  $a$ , the electrochemical equivalent of the element in reference to the compound is

$$\frac{n}{q} \cdot \frac{b}{a},$$

which =  $b\chi$ .

$n$  is of necessity a constant for any given compound: and so is  $b$  in many cases; that is, in such cases, no matter what compound of a particular element be electrolyzed, the same quantity of that element is set free by the passage of a unit of electricity. In other cases, however,  $b$  varies with the character of the compound employed; that is, the same quantity of element is not necessarily always evolved by the passage of a unit of electricity. For example, the value of  $b$  for hydrogen, chlorine, and silver appears to be constantly 1, 35·5, and 108 respectively; whilst for copper the value is 31·75 for compounds of the class known as cupric salts, and 63·5 for compounds of the class known as cuprous salts. When  $b$  is thus variable, its different values are always simple integral multiples of a common divisor.

9. Sir William Thomson calculated in 1851 (*loc. cit. supra*) the value of  $a\chi$  for water on the foot-grain-second electromagnetic system to be as follows:—

From data furnished by experiments of Weber . . .	0·02034
" " " Bunsen . . .	0·02011
" " " " . . .	0·01995
" " " Casselmann . . .	0·02033
" " " " . . .	0·02021
" " " Joule . . .	0·01981
" " " " . . .	0·02030
" " " " " . . .	0·02002
Average . . .	<u>0·02013</u>

On the C.G.S. system (electromagnetic measure) this average value becomes 0·0009282. Stas found that 1 part of hydrogen combines with 7·98 of oxygen to form water, whence  $a=8·98$  for water, and consequently

$$\chi = \frac{0·0009282}{8·98} = 0·00010336.$$

More recent experiments of Kohlrausch (Pogg. *Ann.* cxlix. p. 170) indicate a perceptibly higher value, viz. 0·00010527; for he found that one metre-gramme-second unit of quantity of electricity causes the deposition of 0·11363 gramme of silver, or 1 C.G.S. unit of electricity causes the deposition of 0·011363 gramme of metallic silver; *i.e.*  $b\chi=0·011363$ , whence

$$\chi = \frac{0·011363}{107·93} = 0·00010527,$$

since Stas found the equivalent of silver to be 107·93.

In the same paper Kohlrausch gives the following values for the electrochemical equivalent of water deduced from the experiments of Weber, Bunsen, Casselmann, and Joule, allowance being made for probable errors in the values assigned to the horizontal component of terrestrial magnetism (the numbers are given by him in the metre-gramme-second system):—

Weber . . . . .	0·009396
Casselmann . . . . .	0·009391
Bunsen . . . . .	0·009624
Joule . . . . .	0·009222
Mean . . . . .	<u>0·009406</u>

On the C.G.S. system this value becomes 0·0009406, whence

$$\chi = \frac{0·0009406}{8·98} = 0·00010474.$$

Hence the mean of this value and that deduced by Kohlrausch from his own observations (viz.  $\chi=0\cdot00010527$ ) may be taken as probably the nearest approximation to the truth; *i. e.*  $\chi=0\cdot000105005$ , or practically  $\chi=0\cdot000105$ .

10. If it were possible to obtain a current between the two electrodes of a voltameter or other similar electrolytic cell which would decompose the electrolyte without any disturbance of the thermal equilibrium, then the difference of potential between the electrodes would represent the force of chemical affinity exerted between the products of decomposition in the compound examined; for if  $e$  be the potential-difference (E.M.F. existing between the electrodes) during the passage of a quantity of electricity  $q$ ,  $eq$  units of work will be done. If  $n$  grammes of substance are decomposed, and  $f$  is the work done by the force of chemical affinity in the synthesis of a gramme of substance from the products of decomposition, the total work done is also expressed by  $nf$ , which, by the definition of electrochemical equivalents (§ 8),  $=a\chi qf$ . Hence

$$af = \frac{e}{\chi}.$$

Or "affinity," reckoned per gramme-equivalent, is measured by electromotive force divided by a quantity which is constant; *i. e.* the work done in the synthesis of a gramme-equivalent of substance is expressible by a value indicated in electromotive-force units, just as it is expressible by a value indicated in heat units—the one valuation involving the constant  $\chi$ , the other  $J$ .

11. In practice it is impossible to realize this supposition; for experiment shows that, in the passage of electricity between two electrodes, work is done not only as chemical decomposition but also as heat; by determining the amount of the latter, however, it is easy to calculate how much of the total potential-difference existent between the electrodes is due to the chemical affinity of the constituents: thus, if  $h$  gramme-degrees are evolved during the decomposition of  $n$  grammes of substance of electrochemical equivalent  $a\chi$  by the transfer of a quantity of electricity  $q$ , and if  $E$  represent the total potential-difference existent between the electrodes, the total work done in the electrolytic cell is  $Eq$ , of which  $hJ$  is done as heat. Hence

$Eq - hJ$  is done as chemical decomposition. Let this be equal to  $eq$ , where  $e$  is the E.M.F. representing the chemical affinity to be measured ; then

$$e = E - \frac{hJ}{q} = E - hJ \frac{\alpha\chi}{n},$$

since, by definition of electrochemical equivalents (§ 8),

$$q = \frac{n}{\alpha\chi}.$$

Finally, therefore,

$$e = E - H\chi J,$$

where

$$H = \frac{ha}{n},$$

i. e. where  $H$  is the heat evolved per gramme-equivalent of substance decomposed.

Experiments made in this way (detailed in Part II., *vide* also § 32) have given numbers for the value of  $e$  in the case of water closely corresponding with the value of  $e$  deducible from direct combustion-experiments by the formula arrived at above (§ 10), viz.

$$af = \frac{e}{\chi},$$

which becomes

$$e = af\chi = ah'J\chi = H'\chi J,$$

where  $h'$  is the heat liberated per gramme, and  $H'$  that per gramme-equivalent of water formed by combustion of hydrogen and oxygen.

12. On attentively considering the phenomena attendant on electrolysis, it is evident that it by no means follows that the direct action of the current causes the entire change taking place ; physical changes of state and chemical actions secondary to those due to the action of this current alone may occur ; so that the value of  $e$  thus deduced, although representing the E.M.F. corresponding to the *nett work done* in the sum of the total changes taking place, and consequently representing the "affinity" between the ultimate products in the original compound as above defined, *is not necessarily a measure of the tendency to combine together of the substances primarily formed by the electrolytic decomposition*. For instance, suppose that in

the electrolysis of water the primary products are ordinary gaseous hydrogen and ozone, the latter becoming subsequently transformed (by a secondary chemical action) into ordinary gaseous oxygen : then, since heat is evolved in the conversion of ozone into oxygen to the extent of 14,800 gramme-degrees per 24 grammes of oxygen (Berthelot, *Bull. Soc. Chim. Paris*, 1876, vol. xxvi. p. 56), or 4933 gramme-degrees per 8 grammes of oxygen (corresponding to 9 grammes of water), the value of  $e$  deduced as just indicated will be below the true value by an amount equal to  $\frac{4933}{34100} = 14\cdot 5$  per cent. ; for the negative term in the expression  $E - H\chi J$  will have been overestimated by that quantity.

Again, suppose that the water is brought by a secondary physical action into a quasi-vaporous state before it is decomposed by the current into gaseous hydrogen and oxygen (*e. g.* on the molecular theory of the constitution of matter, suppose that only detached molecules of water are operated on by the current, and not the water *en masse* in the liquid state); since about 600 gramme-degrees are required to volatilize a gramme of water at the ordinary temperature (the latent heat of steam at near  $15^\circ$  being about 600), or 5400 per gramme-equivalent, the value of  $e$  deduced as above will be too large by about  $\frac{5400}{34100} = 15\cdot 8$  per cent, because in this case the negative term  $-H\chi J$  will be underestimated to that extent.

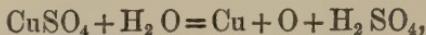
Consequently, if both secondary actions be supposed to take place (*i. e.* if the electrolysis proper takes place between detached molecules of water converting them into gaseous hydrogen and ozone), the value of  $e$  will be  $15\cdot 8 - 14\cdot 5$ , or  $1\cdot 3$  per cent. too large.

Suppose, again, that the primary electrolytic action is to convert liquid water into *liquid* oxygen and hydrogen, and that the conversion of these liquefied elements into the ordinary gaseous condition is due to secondary physical changes ; it is evident that the value of  $e$  found as above is too large by

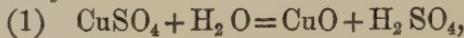
$\frac{h_1}{34100} \times 100$  per cent., where  $h_1$  represents the heat that is absorbed in the vaporization of a gramme-equivalent of each of the liquefied gases taken together.

Yet again, in the electrolysis of copper sulphate, suppose

that whilst the ultimate chemical change is expressed by the equation



this change is actually the sum of two changes, of which the first is secondary:—

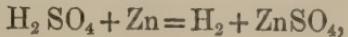


it is evident that the value of  $e$  deduced as above will be greater than that corresponding to the second change only, by an amount equivalent to the heat absorbed during the first change.

13. During the last three or four years the writer has made various experiments with the view of determining the E.M.F. measuring the "affinity" between various constituents in different compounds (especially oxygen and hydrogen in water), not only when the substances developed by the electrolysis are in their ordinary conditions, but also when they are "nascent"—*i. e.* with the view of determining, first, the E.M.F. corresponding to the "heat of formation" of (for instance) water from gaseous oxygen and hydrogen, and, secondly, that requisite to produce electrolysis proper *apart from secondary physical and chemical changes*. It is evident that, if such determinations are practicable, the comparison of the two sets of values might lead to interesting conclusions as to the nature of these secondary actions, and might throw light on the internal mechanism of the chemical changes taking place, and especially on the phenomena connected with the "nascent state." Results in this direction have already been obtained by Favre, with this difference, that the values are expressed in gramme-degrees, being obtained entirely by calorimetric observations. The discussion of the observations of this kind already made by previous experimenters, and of the writer's results (obtained chiefly by electrical measurements), will be resumed in a future paper, the present essay having chiefly reference to the determination of the E.M.F. representing the sum of the physical and chemical actions taking place during electrolysis. It should, however, be noticed in connexion with this subject, that since Sir William Thomson first sketched out the Mechanical Theory of Electrolysis (*loc. cit. supra*), more exact measurements have shown that the E.M.F. actually capable of being generated by a given voltaic combination is by no

means necessarily equal to the sum of the physical and chemical changes taking place in the pile, and that it is not necessarily constant for the same ultimate chemical change—varying with the temperature, the state of dilution of the solutions used, &c.

14. For example, when zinc is dissolved in dilute sulphuric acid, the total ultimate change is expressed by the equation



which corresponds to an evolution of somewhat more than 18,000 gramme-degrees per gramme-equivalent of zinc dissolved or of hydrogen liberated, and representing therefore about  $18000 \times 0.000105 \times 42 \times 10^6 = 0.794 \times 10^8$  C.G.S. units of E.M.F., or about 0.794 volt. Similarly, when zinc or any analogous metal is dissolved in any other acid (*e. g.* hydrochloric) with evolution of hydrogen by a parallel reaction, a heat-evolution of  $h$  gramme-degrees results per gramme-equivalent, corresponding to  $h\chi J$  C.G.S. units of E.M.F. But when this change takes place in an electromotor with a second metal as the other plate, the E.M.F. actually set up by the tendency to produce this ultimate change varies with the nature of the second metal; and whilst the E.M.F. produced is rarely, if ever, precisely equal to  $h\chi J$  even at first, when a current has been made to circulate for some short time the E.M.F. is found to have diminished to an amount depending on the rate of evolution of hydrogen on the surface of the other plate, the character of its surface, the temperature, &c. This is usually expressed by saying that the plates become "polarized," or that a "counter electromotive force"  $x$  is set up, diminishing the effective E.M.F. of the arrangement from  $E$ , which it was at first, to  $E - x$ , the value of  $x$  varying with circumstances.

From the principle of the conservation of energy it results that, when the current circulates, the difference between the work  $h\chi J \times Q$  which would be performed during the passage of a quantity of electricity  $Q$  sufficient to decompose a gramme-equivalent of substance, and  $(E - x)Q$  the work which the current can actually perform, must make its appearance as sensible heat. If, therefore,  $E - x < h\chi J$ , the electromotor must rise in temperature from this cause—irrespective of the rise due to the fact that, as the current traverses the electromotive

equally with the rest of the circuit, heat is developed therein in proportion to its resistance in accordance with Joule's law (§ 1). If, however,  $E - x > h\chi J$ , the battery is of necessity proportionately cooled ; and if the experiment is so carried out that the resistance of the battery is small compared with that of the rest of the circuit, so that the heat developed in the battery in accordance with Joule's law is but small, the cooling effect may be made to preponderate over the heating effect, so that an absorption of heat on the whole takes place in the battery.

15. This effect has been experimentally studied by Favre (*Comptes Rendus*, lxvi. p. 252, lxvii. p. 1012, lxviii. p. 1300, and lxix. p. 34), who has shown that under the last-named conditions an absorption of heat takes place during the solution of zinc or cadmium in hydrochloric acid, whilst heat-evolution takes place if sulphuric acid be substituted for hydrochloric. In other words, the secondary actions set up, as a whole, absorb heat in the first case and evolve it in the second. Similarly in two-fluid batteries, such as Daniell's and Grove's, analogous results were obtained, although in these cases "polarization" by evolution of hydrogen could not possibly be produced. With cells after Daniell's construction heat was found to be evolved by the secondary actions, though not to a very large extent (about 4·3 per cent. of the heat due to the consumption of zinc and precipitation of copper); whilst with a Grove's battery a considerably larger heat-absorption took place, amounting to about 11·9 per cent., of the heat due to solution of zinc and reduction of nitric acid.

16. This result with a Daniell cell is borne out by experiments of a different kind. The E.M.F. which a Daniell cell is practically capable of giving has been variously estimated by different observers, at from 1·05 to 1·14 volt, 1·10 to 1·12 being a usual average. The E.M.F. corresponding to the heat evolved in the reaction



(which expresses the ultimate change in a Daniell cell, apart from local action) is several per cent. higher. Thus Favre estimated the heat thus evolved per gramme-equivalent to be 27,388 (*Comptes Rendus*, lxiii. p. 369), and subsequently as 25,060 (*ibid.* lxix. p. 35) : the mean of these two numbers is

26,224, corresponding to an E.M.F. of  $26,224 \times 0.000105 \times 42 \times 10^6 = 1.156 \times 10^8$  C.G.S. units, or 1.156 volt. Julius Thomsen has calculated (*Berichte deut. chem. Ges.* 1872, vol. v. p. 170) from his own determinations, together with those of Andrews, Dulong, Hess, and Favre and Silbermann, that the heat-evolutions taking place during the formation of zinc sulphate and copper sulphato are respectively 108,460 and 56,216 per "gramme-molecule" (these formations being expressed in Thomsen's symbols thus—Zn, O, SO<sub>3</sub>, aq, and Cu, O, SO<sub>3</sub>, aq). Hence the heats are 54,230 and 28,108 per gramme-equivalent; whence the displacement of copper from copper sulphate by metallic zinc, forming copper and zinc sulphate, must give rise to an evolution of 54,230—28,108=26,122 gramme-degrees per gramme-equivalent, corresponding to  $26,122 \times \chi J = 1.152$  volt.

17. Results analogous to those of Favre have also been obtained by Raoult (*Ann. de Chim. et de Phys.* 4th series, ii. p. 317, and iv. p. 392)—some forms of voltaic combinations giving rise to the production of more heat outside the battery than corresponds to the heat evolved by the ultimate chemical and physical changes taking place therein, and others to less. Raoult found that the current from the Daniell cell used by him was capable of doing total work equal to 23,900 gramme-degrees per gramme-equivalent of zinc dissolved in each cell: this represents only  $23,900 \times \chi J = 1.054$  volt, a quantity less by 8.5 per cent. than the value calculated above from Thomsen's figures as the E.M.F. corresponding to the sum of the chemical and physical actions taking place in the cell.

To express the difference between the heat actually producible by the sum of the chemical and physical actions taking place in an electromotor and that corresponding to the current actually obtainable from the electromotor, Raoult calls the first the *chemical heat* of the pile, and the latter the *voltaic heat* thereof; whilst the terms *chemical heat* and *galvanic heat* have been employed by Edlund to indicate these quantities respectively (*Phil. Mag.* 1877, vol. iii. pp. 428 & 501); so that the above results may be indicated by saying that the chemical heat of a Daniell battery is 26,122 gramme-degrees (per gramme-equivalent of zinc dissolved), whilst the voltaic or galvanic heat is 23,900, and so on. Several points touched

upon in these papers are of interest as bearing on the problem of the determination of the amount of E.M.F. corresponding to the primary effects of electrolysis ; their discussion, like that of several analogous memoirs by previous observers, is postponed till a later occasion.

18. In order to apply the general method above indicated (§ 11) for the determination of the E.M.F. corresponding to the sum of the chemical and physical actions taking place during electrolysis, it is requisite to determine :—first, the difference of potential subsisting between the electrodes ; secondly, the quantity of electricity passing in a given time (known from the weight of substance decomposed) ; and, thirdly, the heat evolved as such in the electrolytic cell in that time. The first quantity may be found approximately by the aid of a sine galvanometer of very high resistance. A method which is in principle substantially this has already been used by Raoult (*loc. cit.*) ; this will be more fully discussed further on (§ 23).

Another way of determining it may be based upon observations with a voltameter, thus :—The amount of decomposition produced in a given time  $t$  by passing a current from the battery employed (of E.M.F. =  $E'$ ) through the voltameter is noticed =  $n_1$  ; the electrolytic cell is then placed also in circuit, and the amount of decomposition in the voltameter in the same time  $t$  again determined =  $n_2$ , and also the heat produced in the cell =  $h$ .  $R$  being the resistance of the battery, voltameter, and connexions, and  $r$  being the resistance of a wire “obstructing the current equally with the electrolytic cell,” the currents flowing in the two cases are respectively

$$C_1 = n_1 \times k = \frac{E'}{R} \text{ and } C_2 = n_2 \times k = \frac{E'}{R+r},$$

where  $k$  is a constant—whence

$$\frac{R}{R+r} = \frac{n_2}{n_1}, \text{ and } \frac{r}{R+r} = \frac{n_1 - n_2}{n_1}.$$

The difference of potential set up between two points connected by a medium of resistance  $r$  traversed by a current  $C_2$  is

$$rC_2 = \frac{r}{R+r} E' = \frac{n_1 - n_2}{n_1} E';$$

and hence the expression for the E.M.F. equivalent to the affinity to be found,  $E - H\chi J$ , becomes

$$\frac{n_1 - n_2}{n_1} E' - \frac{h\chi J}{n_2},$$

where  $\alpha$  is the equivalent of water = 8.98.

19. Experiments on the electrolysis of water have been made by the writer in accordance with this method, and have furnished moderately concordant results approximating to the value of the E.M.F. representing the affinity to be measured, calculated from the heat of combustion of hydrogen (§ 32); but as the experimental errors attendant on the method are considerably greater than those involved when the value of

$\frac{r}{R+r} E'$  is directly determined by means of a quadrant electrometer, this latter mode of operating has been adopted in preference : the details of observations thus made in the case of water are given in Part II. Meanwhile it is of interest to notice that if a tangent galvanometer be substituted for a voltmeter (the quantity of electricity passing being determined by observing the quantity of electrolyte  $w$  decomposed whilst a quantity of heat  $h$  is evolved), the value of the affinity to be determined is given by the analogous formula

$$e = \frac{\tan \alpha - \tan \beta}{\tan \alpha} E' - \frac{h\chi J}{w},$$

where  $\alpha$  and  $\beta$  are the deflections observed with the currents  $C_1$  and  $C_2$  respectively. The experiments of Joule above referred to (Phil. Mag. vol. iii. p. 481), although made for the purpose of calculating the heat of formation of water, copper sulphate, and zinc sulphate in a wholly different way, contain the data requisite for the application of this mode of observation, based on the use of the tangent galvanometer; it being taken for granted that  $E'$ , the value of the E.M.F. of the Daniell battery used, was  $m \times 1.10$  volt, where  $m$  is the number of cells used in the experiment recalculated. Thus, Joule found the following numbers in a series of four observations on the electrolysis of water in which six Daniell cells were used :—

	Mean tan $\alpha$ .	Mean tan $\beta$ .	Gramme of H evolved.	Rise of thermometer.
	3.4170	1.6234	0.03978	40.6 scale divisions.
	3.9429	1.7780	0.04212	37.8      "      "
	4.3412	1.8374	0.04372	41.7      "      "
	4.0508	1.8011	0.04411	38.8      "      "
Average .....	3.9380	1.7600	0.04243	39.725
		Correction for radiation... + 0.656		
				40.381

The water-equivalent of the calorimeter was found to be 1155 grammes, whilst 23.38 scale-divisions of the thermometer represented 1°; hence

$$h = 1994.9.$$

The E.M.F. of affinity to be found, then, is

$$\frac{3.9380 - 1.7600}{3.9380} \times 6 \times 1.10 \times 10^8 - \frac{1994.9 \times 1 \times 0.000105 \times 42 \times 10^6}{0.04243},$$

or

$$1.577 \times 10^8 \text{ C.G.S. units} = 1.577 \text{ volt.}$$

The value deduced from Joule's own figures by his mode of experimenting is 34,101 gramme-degrees per gramme-equivalent of water decomposed, representing  $34101 \times \chi J = 1.504$  volt; whilst the value deducible from the best determinations of the heat evolved in the combustion of hydrogen is 34,100, representing 1.504 volt (§ 32). In two other similar sets of observations, Joule obtained the values 34,212 gramme-degrees corresponding to 1.509 volt, and 32,356 gramme-degrees corresponding to 1.427 volt. Unfortunately the data for recalculating these values, as has just been done with the first set, are not given in his paper; still the difference between the values of the E.M.F. of affinity, calculated as above and from Joule's heat-values, is apparently no greater than the differences observed in these latter on repetition. It is noticeable that a small error in the value of the E.M.F. of the battery produces a much larger error in that of the calculated result: thus, if in the set of observations recalculated as above the E.M.F. of a Daniell cell be taken as 1.08 instead of 1.10 volt, the calculated E.M.F. of affinity comes out 1.511 instead of 1.577 volt; i. e. a diminution of less than 2 per

cent. in the value of the Daniell cell makes a diminution of more than 4 per cent. in the E.M.F. of affinity.

20. In just the same way Joule's experiments on copper sulphate and zinc sulphate may be applied by means of the above formula. Thus with copper sulphate the following numbers were obtained, a battery of 4 Daniell cells being used :—

	Mean tan $\alpha$ .	Mean tan $\beta$ .	Gramme of copper deposited.	Rise of thermometer.
	3·4006	0·7275	0·5686	20·4
	3·7510	0·7535	0·5777	19·4
	3·8538	0·7650	0·5881	19·45
	3·8084	0·7968	0·6153	17·4
Average .....	3·7035	0·7607	0·5874	19·162
		Correction for radiation ...		- 0·049
				19·113

In these experiments the water-equivalent of the calorimeter was 1179·2, whence  $h=963·99$ ,

and the E.M.F. representing the total chemical and physical changes is

$$\frac{3·7035 - 0·7607}{3·7035} \times 4 \times 1·10 \times 10^8 - \frac{963·99 \times 31·75 \times \chi J}{0·5874},$$

or  $1·198 \times 10^8 + 10^8$  C.G.S. units or 1·198 volt.

With zinc sulphate the following numbers were obtained, a battery of 7 Daniell cells being used :—

	Mean tan $\alpha$ .	Mean tan $\beta$ .	Gramme of zinc deposited.	Rise of thermometer.
	3·5500	0·7167	0·5797	32·2
	4·0133	0·7092	0·5647	30·0
	3·8356	0·7573	0·6010	31·3
	3·9025	0·7548	0·5991	30·5
Average .....	3·8254	0·7345	0·5861	31·0
		Correction for radiation ...		- 0·016
				30·984

In these experiments the water-equivalent of the calorimeter was 1180·9, whence  $h=1565$ ,

and the E.M.F. to be found is

$$\frac{3·8254 - 0·7345}{3·8254} \times 7 \times 1·10 \times 10^8 - \frac{1565 \times 32·5 \times \chi J}{0·5861},$$

or

$$2.395 \times 10^8 \text{ C.G.S. units,} = 2.395 \text{ volts.}$$

21. These numbers 1.198 and 2.395 volts lie close to those calculated from Joule's figures by his own method of experimenting, and also to those calculated from the heat evolved in the synthesis of copper and zinc sulphates from the metal, oxygen, and dilute sulphuric acid; these latter quantities were found by Thomsen (*Deut. chem. Ges. Berichte*, 1872, vol. v. p. 170) to be respectively 56,216 and 108,460 per "gramme-molecule," or 28,108 and 54,230 per gramme-equivalent. A somewhat smaller number than the former of these (viz. 26,568) was found by Favre for the "heat of formation" of copper sulphate from copper, oxygen, and dilute sulphuric acid by the method referred to in § 5. These various results may be thus contrasted:—

Copper Sulphate.				
Observers furnishing the principal data for calculation.	Nature of method of calculation.	Heat evolved.		E.M.F. of affinity in volts (1 volt = $10^8$ C.G.S. units).
		Per gramme of metal deposited.	Per grm.-equivalent of metal deposited.	
Joule .....	{ Joule's own method, described in §§ 2 & 3.	836.4	26556	1.171
		856	27178	1.199
		796.5	25289	1.115
		829.6	26341	1.162
Joule .....	{ From formula $e = E - H_X J$ (§ 11).	.....	.....	1.198
Julius Thomsen	{ From formula $e = H' X J$ (§§ 10 & 11).	.....	28108	1.240
Favre .....	"	.....	26568	1.172
Zinc Sulphate.				
Joule .....	{ Joule's own method (§§ 2 & 3).	1523.1	49501	2.183
		1547	50277	2.217
		1619	52617	2.320
		1563.0	50798	2.240
Joule .....	{ From formula $e = E - H_X J$ (§ 11).	.....	.....	2.395
Julius Thomsen	{ From formula $e = H' X J$ (§§ 10 & 11).	.....	54230	2.392

22. In reference to Julius Thomsen's values, it is noticeable that some slight uncertainty in the precise values of the heat-developments in the syntheses  $\text{Cu}_2\text{O} + \text{SO}_3\text{aq.} \rightarrow \text{CuSO}_4\text{aq.}$  and  $\text{Zn}_2\text{O} + \text{SO}_3\text{aq.} \rightarrow \text{ZnSO}_4\text{aq.}$  is introduced by the circumstance that these values are calculated from determinations of the heat evolved by the direct combustion of metal to oxide, and that produced by solution of the metallic oxide in dilute sulphuric acid—these determinations being made by different observers necessarily working with different specimens of metallic oxides, and their results being averaged. Ditte has shown, however (*Comptes Rendus*, lxxii. pp. 762 & 878, and lxxiii. p. 108), that the heat developed by dissolving a metallic oxide in an acid varies with the degree of heat to which the oxide has previously been exposed. Thus, with zinc oxide and dilute sulphuric acid, the following values were obtained per gramme-equivalent:—

	Gramme-degrees.
Zinc oxide previously heated to $350^\circ$ . . . . .	9,890
"      "      "      dark red heat .	11,016
"      "      "      bright   , .	12,138

The value of this "heat of solution" was given by Favre as 10,455, and by Julius Thomsen as 11,705, the temperature to which the zinc oxide had been previously heated not being stated.

23. The experiments of Raoult above adverted to (§ 18) were conducted as follows:—A current from a Daniell battery was passed through a galvanometer and a voltameter placed in a calorimeter, a derived circuit containing a sine galvanometer being also applied to the voltameter-plates; so that the current in this derived circuit virtually measured the difference of potential subsisting between the voltameter-plates. Calling  $f$  the "intensity of the derived current," and  $d$  that due to a Daniell cell working through the same resistance, and taking 23,900 as the "galvanic heat" (§ 17) of each Daniell cell used, the total work done in the voltameter per gramme-equivalent will be represented by  $\frac{f}{d} \times 23,900$  gramme-degrees: subtracting this from the heat actually developed as such, a value in gramme-degrees is obtained representing the work done as chemical decomposition. In this way Raoult ob-

tained the following values for the chemical decomposition of water and copper sulphate:—

Water.		Copper sulphate.
33,858	gramme-degrees.	30,407 gramme-degrees.
34,229	" "	29,765 " "
33,998	" "	29,683 " "
Mean .	34,028	29,951 " "

These mean values correspond respectively to  $34,028 \chi J = 1.501$  volt and  $29,951 \chi J = 1.321$  volt. The former number closely agrees with the above-cited results of Joule, Kiechl, and Favre, and with the number deduced by direct combustion of hydrogen (§ 32); the latter is somewhat larger than the values deducible from the observations of Joule, Julius Thomsen, and Favre, given in § 21.

The mode of calculation employed by Raoult, however, was far less simple than would appear from this brief account of his results. He complicated the work by attempts to measure the amount of polarization set up in the voltameter; and from the numbers thus obtained, together with the strengths of the derived currents and the amounts of heat actually generated as such, he calculated certain amounts of heat, to which he applied the terms "local heat" and "voltaic heat of the voltameter," the difference between which represented the heat equivalent to the chemical decomposition—*i. e.* the above numbers. On revising his formulæ, however, it becomes evident that the determination of the amount of polarization of the voltameter-plates (a determination the accuracy of which is open to some criticism) is in no way involved in the determination of the heat equivalent to the chemical decomposition, inasmuch as the terms involving the amount of polarization in the expressions for the "local heat" and the "voltaic heat of the voltameter" are identical, and consequently become both eliminated in the expressions representing the difference between these two quantities—*i. e.* the chemical decomposition.

24. It is evident that any method that will give a direct valuation by electrical measurements of the work done in the formation of a given compound in terms of E.M.F. will, when compared with the direct determination of the "heat of

formation" of the same compound by means of the calorimeter, enable a new valuation to be deduced for  $J$ , the mechanical equivalent of heat; for the work done in the formation of a gramme-equivalent of the compound being found by the one method to be measured by  $e$  C.G.S. units, and by the other by  $h$  gramme-degrees, the relationship

$$hJ = eQ = \frac{e}{\chi}$$

holds, where  $Q$  is the quantity of electricity requisite to decompose a gramme-equivalent of substance, *i.e.* where  $Q = \frac{1}{\chi}$  ( $\S 7$ ); whence

$$J = \frac{e}{h\chi}.$$

If, however, the value of  $J$  is included in the value of  $e$ , as is necessarily the case when  $e$  is calculated by the formula  $e = E - H\chi J$  ( $\S 11$ ), this formula becomes

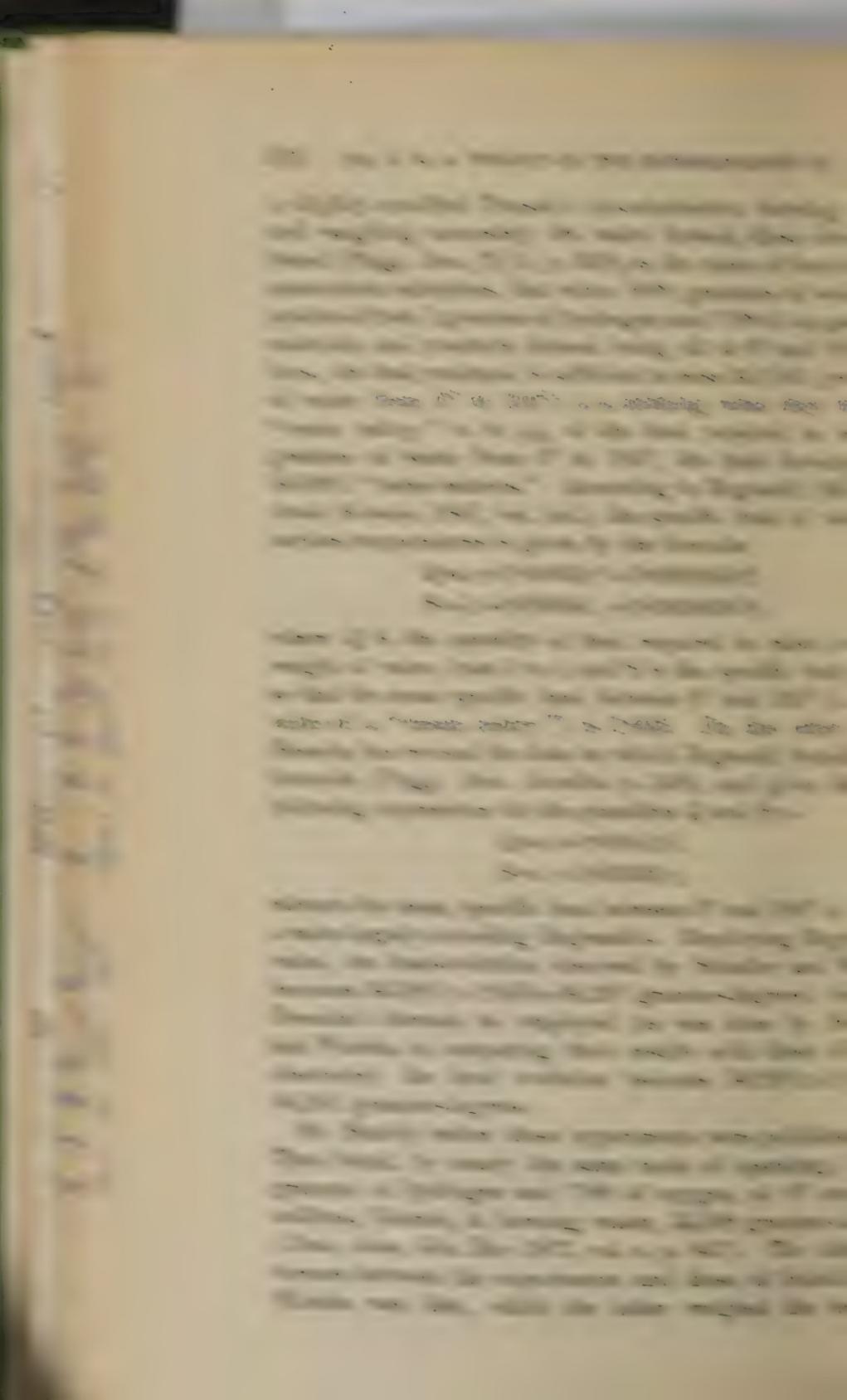
$$hJ = \frac{E - H\chi J}{\chi},$$

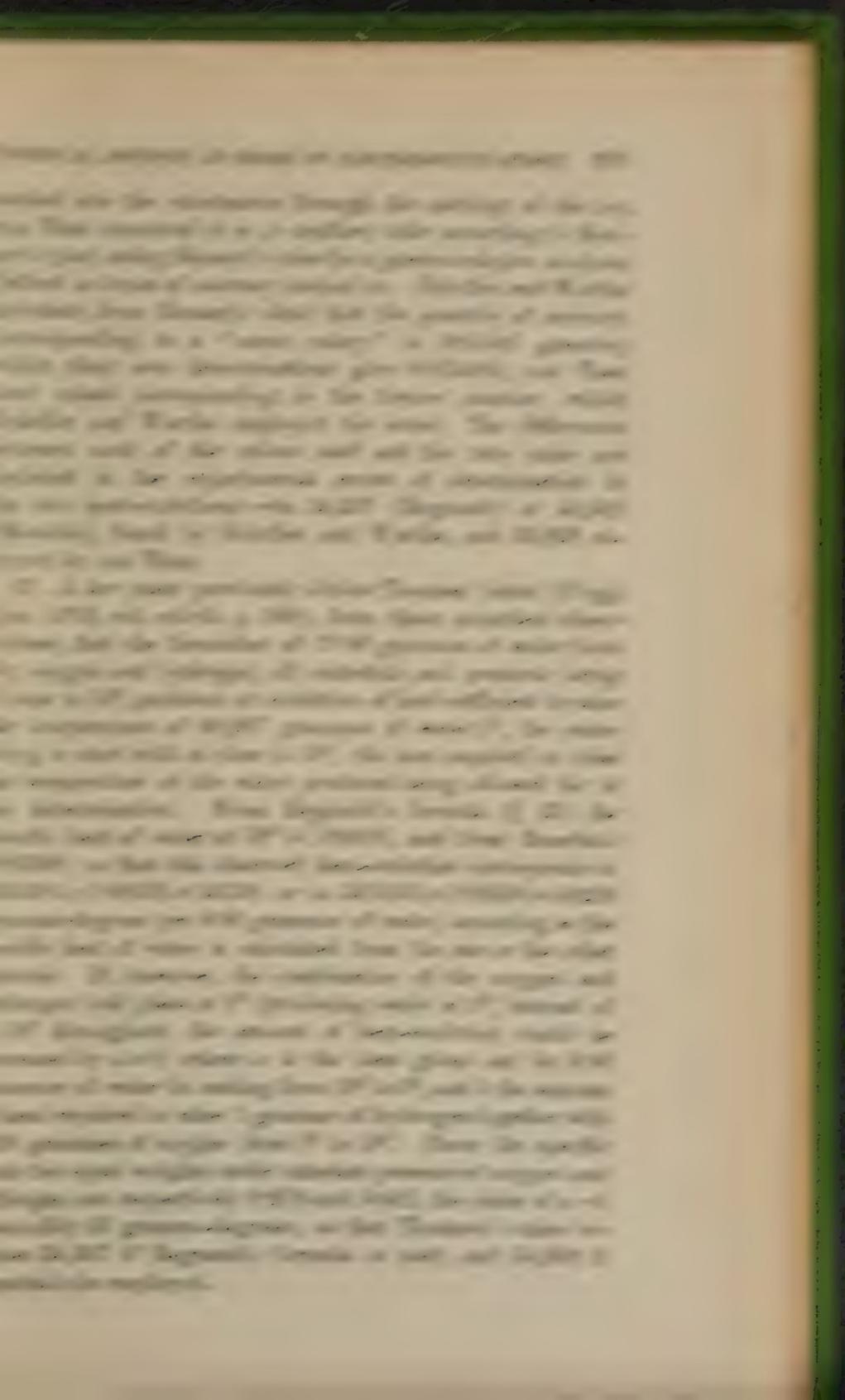
whence

$$J = \frac{E}{(H + h)\chi}.$$

25. In the case of water, a number of determinations of  $h$  (the heat evolved by the union of oxygen and hydrogen by combustion) have been made by various observers, but for the most part with slightly different values for the heat unit. Leaving out of sight the first approximate determinations of Dulong, Hess, and Grassi (respectively 34,743, 34,792, and 34,666 gramme-degrees per 9 grammes of water formed), the following comparisons of these different determinations may be made, reducing them all, as far as possible, to the same conditions—viz. supposing the oxygen and hydrogen originally used per gramme-equivalent of water (respectively 7.98 and 1 gramme) and the water produced (8.98 grammes) to be all at  $0^\circ$  and 760 millims., the value of a gramme-degree being defined as the heat required to raise 1 gramme of water from  $0^\circ$  to  $1^\circ$  C.

The most recent of these determinations is that of Schuller and Wartha. By introducing hydrogen and oxygen at  $0^\circ$  into





28. Favre and Silbermann found (*Annales de Chimie* [3], xxxiv. p. 357) that when 9 grammes of water were formed from oxygen and hydrogen, the gases being at a mean temperature of  $9^{\circ}$  (at  $6^{\circ}$  to commence with and  $12^{\circ}$  to end with), and the water produced being at  $6^{\circ}$  (the heat required to raise the temperature of the water produced being taken into account in determining the water-equivalent of the calorimeter), the average heat-evolution sufficed to raise 34,462 grammes of water  $1^{\circ}$ , the water being at the average temperature of  $9^{\circ}$ . According to Regnault's formula the specific heat of water at  $9^{\circ}$  is 1.00043, and according to Bosscha's 1.00198; whence the heat-evolution per 8.98 grammes becomes

$$\frac{8.98}{9} \times 34462 \times 1.00043 = 34400,$$

or

$$\frac{8.98}{9} \times 33462 \times 1.00198 = 34453,$$

according as the one or the other formula is used. To this must be added a quantity  $c-d$  to reduce the value to that which would have been produced had the gases and water produced been all at  $0^{\circ}$ :  $c$  is the heat given out by 8.98 grammes of water in cooling from  $6^{\circ}$  to  $0^{\circ}$ , whilst  $d$  is the heat required to raise the hydrogen and oxygen from  $0^{\circ}$  to  $9^{\circ}$ ; whence  $c-d$  is sensibly 8 gramme-degrees. So that the heat-evolution becomes 34,408 by Regnault's formula, and 34,461 by Bosscha's formula.

29. Andrews found (Phil. Mag. 1848, vol. xxxii. p. 321) that a litre of dry hydrogen gas at  $0^{\circ}$  and 760 millims., in combining with oxygen, the gases being at the average temperature of  $19^{\circ}.7$ , produced (on an average of four accordant experiments) enough heat to raise 3036 grammes of water  $1^{\circ}$ , the water being at an average temperature of  $20^{\circ}.7$ , and the calculation not including the heat required to raise the water produced from the average initial temperature of  $19^{\circ}.7$  to the average final temperature  $21^{\circ}.8$ . Since a litre of hydrogen at  $0^{\circ}$  and 760 millims. weighs 0.089578 gramme (Regnault), the corrected heat-evolution per gramme of hydrogen burnt (*i. e.* per 8.98 grammes of water produced) would suffice to heat  $\frac{3036}{0.089578} + 19 = 33,911$  grammes of water  $1^{\circ}$ , the water

being at  $20^{\circ}\text{C}$ . According to Regnault's formula the specific heat of water at  $20^{\circ}\text{C}$  is 1.00122; according to Bosscha's formula, 1.00455. Hence the heat-evolution is  $33911 \times 1.00122 = 33952$  (Regnault's formula), or  $33911 \times 1.00455 = 34065$  (Bosscha's formula). To this must be added a quantity  $e-f$  to reduce the value to that which would have been produced had the gases and water formed been all at  $0^{\circ}\text{C}$ ,  $e$  being the heat given out by 7.98 grammes of water in cooling from  $19^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ , and  $f$  that required to heat up the constituent hydrogen and oxygen from  $0^{\circ}\text{C}$  to  $19^{\circ}\text{C}$ ; so that  $e-f$  is sensibly 76 gramme-degrees; whence finally the heat-evolution becomes 34,028 by Regnault's formula, and 34,141 by Bosscha's formula.

30. These reduced values may therefore be thus contrasted:—

	By Regnault's formula.	By Bosscha's formula.
Schuller and Wartha . . .	34297	34501
Von Than . . . . .	33928	33928
Julius Thomsen . . . . .	34207	34308
Favre and Silbermann . .	34408	34461
Andrews . . . . .	<u>34028</u>	<u>34141</u>
Mean . . . . .	<u>34174</u>	<u>34268</u>

That is, the average of these different determinations indicates that by the combustion of 1 gramme of hydrogen and 7.98 grammes of oxygen to water, the gases and water produced being at  $0^{\circ}\text{C}$  and 760 millims. throughout, the heat produced would raise the temperature of 34,174 or 34,268 grammes of water from  $0^{\circ}\text{C}$  to  $1^{\circ}\text{C}$ , according as Regnault's or Bosscha's formula for the specific heat of water is used. It is noticeable that the latter formula makes Schuller and Wartha's most carefully made experiments appear abnormal, by showing a much greater divergence, both from von Than's (made by essentially the same method) and from the general average, than is the case when Regnault's formula is employed; and hence an additional reason is derived for viewing Bosscha's alleged corrections of Regnault's numbers as being more open to objection than these numbers themselves.

If the combination of the oxygen and hydrogen be supposed to take place at  $20^{\circ}\text{C}$  instead of  $0^{\circ}\text{C}$  (*i. e.* if the gases used and water produced be all at  $20^{\circ}\text{C}$ ), the heat-evolution will be less

than that calculated above by  $g-h$  gramme-degrees, where  $g$  is the heat required to raise 8.98 grammes of water from 0° to 20°, and  $h$  that requisite to raise the constituent gases through the same range, *i. e.* where  $g-h$  = sensibly 77 gramme-degrees. Whence, if water be decomposed at 20° and 760 millims. into oxygen and hydrogen at the same temperature and pressure, the heat-absorption is 34,097, using Regnault's formula, and 34,191 using Bosscha's formula. Similarly at 15°, the correction  $g-h$  would be 58 gramme-degrees, giving the values 34,116 (Regnault's formula), and 34,210 (Bosscha's formula).

31. On the other hand, experiments have been cited above (§§ 2 & 5), made by Joule, Kiechl, Raoult, and Favre, giving the following values for the heat-absorption during the electrolysis of water at the ordinary temperature:—

Joule . . . . .	33557
Kiechl . . . . .	33653
Raoult . . . . .	34028
Favre . . . . .	34204
Mean . . . . .	33860

As these values are mostly calculated per 9 grammes of water, this average value should be reduced in about the proportion of  $\frac{8.98}{9}$ ; but since the increase of temperature of the calorimeter observed represents a slightly higher number of gramme-degrees than that stated, on account of the increase of the specific heat of water with the temperature, the average value requires slightly raising from this cause. After making all probable allowances for these corrections, however, the mean value still remains perceptibly lower than that calculated as above from the results of Schuller and Wartha, von Than, Julius Thomsen, Andrews, Favre, and Silbermann.

On the whole, the data at present extant may be taken to show that when 8.98 grammes of water are formed from gaseous oxygen and hydrogen at the ordinary temperature (15° to 20°) throughout, the evolution of heat is sensibly that required to raise the temperature of 34,100 grammes of water from 0° to 1° C.; or when 1 gramme is formed, the heat-evolution suffices to raise 3797 (or practically 3800) grammes from 0° to 1° C., this value being taken from the reductions by Regnault's

formula as being probably more accurate than those made by Bosscha's alleged corrected formula.

32. A number of observations, the details of which are given in Part II., show that, admitting the accuracy of Latimer Clark's valuation of the E.M.F. of his standard cell (Proc. Roy. Soc. 1872, vol. xx. p. 444) as being  $1.457 \times 10^8$  C.G.S. units at  $15^\circ$ , the value of  $e$  in the expression  $e = E - H\chi J$  (§ 11) is  $1.5003 \times 10^8$  C.G.S. units when water is electrolyzed at a temperature of  $15^\circ - 20^\circ$ , the value of  $J$  being taken as  $42 \times 10^6$ —the probable error of the mean result being  $\pm 0.0048$ , or  $\pm 0.32$  per cent. Owing, however, to certain causes detailed in Part II. (§ 39), this value is slightly too low—this result being essentially due to the impracticability of collecting every trace of gas evolved, so that the value of  $H$  (the heat evolved per gramme-equivalent of water decomposed) is slightly overvalued, and hence  $e$  slightly undervalued.

From the combustion experiments of previous investigators, summarized in the preceding eight paragraphs, it results that the value of  $e$  in the expression  $e = H'\chi J$  (§ 11) is  $1.5038 \times 10^8$  (since  $H' = 34,100$ ),  $J$  being, as before, taken as  $42 \times 10^6$ . These numbers,  $1.5003 \times 10^8$  and  $1.5038 \times 10^8$ , accord so closely as to show that (so far as these experiments can decide) the value of  $J$  cannot be far from  $42 \times 10^6$ . Applying the formula

$$J = \frac{E}{(H + H')\chi}$$

(§ 24) to the experimental data given in Part II., the average value deduced for  $J$  is  $41.96 \times 10^6$ , this value for  $J$  giving the following values for  $e$ :-

$$\begin{aligned} \text{From formula } e &= E - H\chi J \quad \dots \quad e = 1.5023 \times 10^8 \\ \text{, , , } e &= H'\chi J \quad \dots \quad e = 1.5024 \times 10^8. \end{aligned}$$

Since, however, the mean value of  $H$  is slightly overvalued, it results that the value of  $J$  finally deduced is slightly *above*  $41.96 \times 10^6$ , with a probable error of less than  $\pm 0.4$  per cent., *i.e.* of less than  $\pm 0.016 \times 10^6$ , due to the electrolytic experiments, the probable error in the determination of  $H'$  not being taken into account.

33. It is evident that, considering the nature of the data from which this conclusion is drawn, not much dependence

can be placed on the final value of J deduced except as an approximation. It is noteworthy, however, that this value of J very closely agrees with that deduced by Joule in 1867 (B. A. Reports, 1867), by determining the heat producible in a wire of known resistance by a known current, and that both are perceptibly higher than the value obtained by Joule by means of water-friction &c. in 1850 (Phil. Trans. 1850, p. 61); whilst this older value is completely corroborated by his recently made experiments on water-friction &c. (Phil. Trans. 1878, p. 365). In 1850 Joule found that the heat required to raise 1 lb. of water (weighed *in vacuo*) from  $t$  to  $t+1$  (where  $t$  lies between  $55^{\circ}$  and  $60^{\circ}$  F.) corresponded to the following number of foot-pounds at Manchester:—

By friction of water . . . .	772·692
" " mercury . . . .	774·083
" " cast iron . . . .	774·987

Of these values the first was considered probably the most accurate; and as a little vibration and sound was unavoidable in the experiments, the round number 772 was adopted as the most probable value. The 1878 value finally arrived at is that the heat required to raise 1 lb. of water (weighed *in vacuo*) from  $60^{\circ}$  to  $61^{\circ}$  F. corresponds to 772·55 foot-pounds, and is hence sensibly identical with the former result. The 1867 values, however, were as follows, expressed in foot-grain-second units:—

	Per grain degree F. (water weighed in air).
1st series. Mean of 10 experiments . . .	25335
2nd " " 15 " . . .	25366
3rd " " 30 " . . .	25217

Of these the last value was taken as most exact; when reduced to water weighed *in vacuo* it becomes 25187. As in this series the average temperature of the calorimeter was  $18^{\circ} \cdot 63$  C. =  $65^{\circ} \cdot 5$  F., the final result is that, to raise the temperature of 1 gramme of water from  $65^{\circ}$  to  $66^{\circ}$  F., requires 25,187 foot-grain-second units of work.

34. When reduced to C.G.S. measure and degrees Centigrade the three values, 772·692 foot-pounds, 772·55 foot-pounds, and 25,187 foot-grain-second work units, become respectively 41·60, 41·59, and 42·14 megalergs per grammee-

degree, the value of  $g$  at Manchester being taken at 981·3. (Compare illustrations of the C.G.S. system of units, by Prof. Everett, p. 51.) Since, however, the specific heat of the water at the three assigned temperature-limits, 55°–60°, 60°–61°, and 65°–66° F., is not quite the same, on reduction to the gramme-degree taken above as unit (the heat requisite to raise 1 gramme of water from 0° to 1° C.), these values become

$$\frac{41\cdot60}{1\cdot0008} = 41\cdot57, \quad \frac{41\cdot59}{1\cdot0009} = 41\cdot54, \text{ and } \frac{42\cdot14}{1\cdot0010} = 42\cdot10$$

megalergs respectively when Regnault's formula for the specific heat of water (§ 25) is taken; whence the mean value of  $J$  is 41·555 megalergs from the two sets of friction experiments (1850 and 1878), and 42·10 by the electric-current method (1867)—the latter consequently being  $\frac{42\cdot10}{41\cdot555} = 1\cdot0131$  times the former, or 1·31 per cent. in excess. The value for  $J$  deduced above from the writer's experiments (viz.

41·96 megalergs) is  $\frac{41\cdot96}{41\cdot555} = 1\cdot0098$  times that got from Joule's friction experiments, showing an excess of 0·98 per cent. Hence, on the whole, the writer's numbers and Joule's 1867 values concord much more exactly than might have been anticipated, each showing an excess over Joule's water-friction value (1850 and 1878) of about 1 per cent., Regnault's formula being employed for reducing the observed rise of temperature to gramme-degrees at 0°–1° C.

35. Reasons have already been given (§ 32, *vide also* Part II. § 39) for supposing that the value 1·5003 found for the E.M.F. representing the affinity for oxygen and hydrogen in water is slightly understated. The effect of an error of this kind would be to raise the value of  $J$  deduced by the formula

$$J = \frac{E}{(H+h)\chi} \quad (\text{§ 24}),$$

and hence to make the excess of the value of  $J$  thus deduced over Joule's water-friction value to be somewhat more than the 1 per cent. or thereabouts just calculated. It is worthy of notice that there is also reason for supposing that Joule's 1867 value is understated. Experiments are described in Part II. the result of which is to show that an unobserved source of

error existed in Joule's 1867 experiments, the effect of which was to diminish the value of  $J$  thence deduced by an amount probably equal to some tenths per cent.; so that on the whole Joule's 1867 value, when corrected, is probably from 1·5 to 2·0 per cent. higher than his water-friction value (1850 and 1878).

This difference between the two values is precisely that which would subsist did an error to an equal amount exist in the B.A. resistance-unit valuation: *i. e.* if the B.A. unit were 1·015 to 1·020 earth-quadrant per second instead of being exactly 1 earth-quadrant per second, the value of  $J$  deduced from Joule's 1867 experiments would be 1·015 to 1·020 times the true value; for it is calculated by the formula

$$J = \frac{C^2 R t}{H},$$

where  $C$  is the current,  $R$  the resistance,  $t$  the time, and  $H$  the heat evolved. Moreover the existence of such an error in the B.A. unit would cause a precisely corresponding error in Latimer Clark's valuation of the E.M.F. of his standard cell (Proc. Roy. Soc. 1872, vol. xx. p. 444), this valuation being based on the determination of the resistance  $R$  between two points traversed by a known current  $C$ , the potential difference  $E$  between the points being equal to the E.M.F. of the cell, so that by Ohm's law  $E=CR$ ; and the effect of this would be to cause a precisely similar error in the value of  $J$  deduced by the formula  $J = \frac{E}{(H+h)\chi}$ , as in the writer's experiments.

36. In confirmation of the supposition that the B.A. unit of resistance is too large, Kohlrausch's experiments may be cited (Phil. Mag. 1874, vol. xlvii. pp. 294 & 342). A careful comparison of several copies of the B.A. unit with coils standardized by himself in absolute measure led Kohlrausch to the conclusion that the B.A. unit is really 1·0196 earth-quadrant per second, or 1·96 per cent. too large; for he found that the resistance of certain coils graduated in Siemens mercury units averaged  $0\cdot9717 \times 10^9$  C.G.S. units, whilst the B.A.-unit coils averaged 1·0493 times the resistance of the Siemens coils, giving therefore for the B.A. unit the value

$$0\cdot9717 \times 1\cdot0493 \times 10^9 = 1\cdot0196 \times 10^9.$$

On the other hand, it is to be observed that Lorenz has

made a determination of the value of a Siemens mercury unit with a lower result (*Pogg. Ann.* 1873, vol. cxlix. p. 251), viz.  $0\cdot9337$  earth-quadrant per second. Lorenz's mercury-tubes were made by himself; and it does not seem from his paper that any evidence was obtained of the purity of the mercury used other than the fact that its specific gravity at  $5^{\circ}\cdot3$  C. was  $13\cdot586$  after digesting for a long time with nitric acid. These mercury-tubes do not seem to have been compared directly with any B.A.-unit coil so as to give the value of the B.A. unit in absolute measure; on comparing them with a reputed Siemens unit, Lorenz found a difference of nearly 1 per cent. ( $0\cdot943 \times 10^9$  as against  $0\cdot9337 \times 10^9$ )—the difference between Lorenz's mercury-tube value of a Siemens unit and the value of the latter in B.A. units, as deduced by Kohlrausch, being nearly exactly double this amount, or nearly 2 per cent.,  $\frac{1}{1\cdot0493} \times 10^9 = 0\cdot9530 \times 10^9$  as against  $0\cdot9337 \times 10^9$ .

37. Yet, again, values for J have been obtained by other observers considerably higher than that deduced from Joule's water-friction experiments. The following Table (mainly taken from Prof. G. C. Foster's article "Heat" in Watts's "Dictionary of Chemistry," 1st Supplement, p. 687) gives the chief of these results expressed in gravitation measure, no corrections being made for differences in the value of  $g$  at the various localities where the experiments were made, or in the specific heat of water at different temperatures. The last column gives the approximate ratio of the value found to that deduced by Joule from water friction, this latter being taken as  $423\cdot5$  metre-grammes per gramme-degree Centigrade:—

Observer.	Method employed.	Value of J found.	Ratio to Joule's water-friction value.
Hirn .....	Crushing of lead .....	425·2	1·004
	Friction of water and brass.....	432	1·020
	Escape of water under pressure .....	433	1·023
	Specific heats of air .....	441·6	1·043
Joule .....	Heat produced by electric currents .....	429·3	1·014
Violle.....	" " induced currents (aluminium)	434·9	1·027
	" " " " (copper) .....	435·2	1·028
	" " " " (tin) .....	435·8	1·029
	" " " " (lead) .....	437·4	1·033
Regnault...	Velocity of sound .....	437	1·032

On the whole, it is evident that further experiments are desirable as to the development of heat in circuits of resistance measured in terms of the B.A. unit by known currents, so as to establish as accurately as possible a connexion between the values of  $J$  and of the B.A. unit, so that if the first is assumed to be correctly given by Joule's water-friction value the error (if any) in the B.A. unit can be calculated, or so that the value of  $J$  can be determined afresh when the precise value of the B.A. unit is known from further experiments. The writer hopes shortly to be enabled to communicate the results of experiments in this direction made by a method differing from that employed by Joule in certain important points, so as to avoid the sources of error existent in Joule's 1867 experiments (Part II.).

**PART II.**—*By Dr. C. R. ALDER WRIGHT and E. H. RENNIE,  
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*Experimental Determination of the Electromotive Force corresponding to the Work done in the Decomposition of Water into Oxygen and Hydrogen at the ordinary temperature.*

38. In order to apply the principles described in Part I. (§§ 11, 18, 32), the current from a Daniell battery was passed through a voltameter placed in a calorimeter, and the average difference of potential between the voltameter-plates determined by connecting them with a quadrant electrometer standardized by a Clark cell (verified for us by Dr. Alexander Muirhead). The amount of decomposition being determined ( $= n$  grammes), and the quantity of heat,  $h$ , developed in the voltameter observed, the data were obtained for the calculation of the E.M.F. representing the nett work corresponding to the sum of the physical and chemical changes taking place by the formula

$$e = E - \frac{h\chi J}{n},$$

$\alpha$  being the equivalent of the electrolyte.

In the case of water acidulated with sulphuric acid, the following results were obtained. The voltameter consisted of

a wide test-tube of about 30 millimetres diameter, into the neck of which was fixed an india-rubber cork perforated with three holes: through the centre one passed a delivery tube of small bore for the collection of the evolved gases; through the other two, copper rods 5–6 millims. in diameter. To the lower ends of these were soldered equally thick platinum rods, the free ends of which were previously forged into spade-like plates which were arranged parallel to one another; the solderings and the portions of the copper rods inside the test-tube were imbedded in a thick mass of gutta-percha, with the three-fold object of keeping the plates at an invariable distance from one another (the voltameter being also intended for some other experiments in which this was essential), of protecting the copper and soldering from corrosion by the acid and the consequent introduction of metals into the solution electrolyzed, and of filling up the upper space in the tube, so that any error due to alteration in temperature of the voltameter and consequent retention therein of varying quantities of gas should be rendered negligible. The projecting ends of the rods were passed through small india-rubber corks and amalgamated; by then fixing short pieces of wide glass tubing over these smaller corks and pouring mercury into the cups thus formed, connexion by mercury-cups could readily be established between the battery and the voltameter-plates.

This arrangement of mercury-cups was also applied to the copper Daniell-battery cells, a thick wire bent downwards and amalgamated at the end being also soldered to each zinc plate so as to dip into the mercury-cup of the next cell. Much trouble in brightening connexions &c. was thus saved; the current could readily be broken instantaneously by simply lifting one of the zinc plates an inch or so, so that the wire no longer dipped into the mercury; whilst an easy means was afforded of introducing more cells or shutting some out from the circuit when required without actually interrupting the current.

39. A number of attempts were made to utilize Bunsen's ice-calorimeter for the measurement of the heat evolved; the construction of apparatus sufficiently large to enable considerable amounts of heat to be measured accurately, however, was found to present some difficulties; whilst with smaller apparatus the errors of measurement of the amount of gas

evolved became considerable, even when the voltameter was connected with the gas-measuring apparatus used for Frankland and Armstrong's water-analysis process; for the occlusion of the evolved gases by the electrodes, the absorption of oxygen by the acidulated water of the voltameter, the production of ozone or of hydrogen dioxide, and the removal of hydrogen whilst still nascent from the one electrode by combination with dissolved oxygen, and of oxygen from the other by combination with dissolved hydrogen, present sources of diminution in the amount of gas actually evolved, which mostly become relatively greater with weak currents, such as would have to be employed with a small ice-calorimeter. Although it did not appear to be impracticable to overcome these difficulties, yet it was found that to do so would require a considerable amount of time and trouble; and therefore we reverted to the use of an ordinary water-calorimeter, employing currents of sufficient magnitude to furnish upwards of 500 cub. centims. of mixed gases during the time which the experiment lasted (from ten to forty-five minutes, according to the battery power used). Even with the strongest currents used, representing about 0·65 C.G.S. current-unit, the amount of substances formed capable of liberating iodine from potassium iodide corresponded to no more than ·001 to ·002 gramme of iodine per 500 cub. centims. of gas produced, representing a diminution in the volume of gas evolved practically quite inappreciable. The gas-measuring apparatus in our possession being incapable of measuring so large a quantity as 500 cub. centims., we employed the method used by Joule for determining the volume of gas produced, viz. collection over water in a bottle, the weight of which was known when filled with water and closed by a stopper. To determine the gas collected, the bottle was immersed for some minutes in a large bucket of water, the temperature of which was known; when the gas had attained the temperature of the water, the bottle was raised until the level of the fluid inside and out was the same (*i. e.* until the pressure was atmospheric); the stopper was then inserted and the bottle removed, wiped dry, and weighed. In this way a close approximation to the quantity of gas produced was obtained, the error being one of defect, owing to the sources above mentioned and the absorption

of oxygen by the water during the process of collection. From the number of cub. centims. of mixed gases thus obtained (reduced to dryness, 0° C., and 760 millims.) =  $v$ , the weight of water decomposed,  $w$ , was calculated by the formula

$$w = v \times 0.0005363,$$

the coefficient 0.0005363 being deduced from Regnault's observations that 1 litre of dry hydrogen and oxygen at 0° and 760 millims. weigh respectively 0.089578 and 1.429802 gramme,

whence 2 grammes of hydrogen occupy	22.327 litres,
and 15.96      , ,      oxygen      "	11.162      , ,

so that 17.96 grammes of detonating gas occupy 33.489      , ,

or 1 cub. centim. of detonating gas weighs  $\frac{17.96}{33489} = 0.0005363$  gramme.

40. The calorimeter employed in these experiments consisted of a glass beaker capable of holding about 1500 cub. centims., fitted closely inside a polished tin cylinder supported (on a wooden block and several folds of wadding) concentrically inside a similar tin cylinder, so that about an inch of air-space everywhere intervened between the two tin surfaces, the two tin cylinders being kept in the same relative positions by cork wedges. This outer cylinder was weighted with lead and sunk inside a third similar larger cylinder filled with water; so that the calorimeter itself was surrounded on all sides, saving the top, by a water jacket. Polished tin lids for the calorimeter and the outermost vessel were provided, perforated with holes for the passage of the voltameter (in the axis of the cylinders), of the thermometers employed, and of the stirrers; these latter consisted of annular horizontal metallic plates, with stout vertical wires attached, so that by moving them up and down a very effective agitation could be accomplished. The thermometers were graduated in millimetres, and were carefully calibrated and checked against one another and against a Kew-standardized thermometer. The one used for the inner vessel was found to be sensibly uniform in calibre at the part where the observations were made (chiefly that corresponding to 12°–20° C.); and at this part the value of 1° C. was 11.28

millims. Several careful determinations of the water-equivalent of the calorimeter (including the stirrer, thermometer-bulb, and voltameter, which always contained 20 grammes of acidulated water containing 22 per cent. of  $H_2SO_4$ ,) gave numbers varying from 1092 to 1097, and averaging 1094·5 grammes when 1000 grammes of water (weighed in a vacuum) were placed therein.

41. In order to obtain with as great a degree of accuracy as possible the corrections for radiation with this instrument, a large number of observations were made of the rate of alteration of the reading of the calorimeter-thermometer under various conditions, viz. when the water jacket was hotter or colder than the calorimeter, and when the calorimeter was warmer or colder than a thermometer-bulb placed a few inches above the outer lid, so as to indicate the temperature of the air together with the effect produced by radiation from the hand during stirring. It was found that all the observations could be expressed with a fair degree of accuracy by the formula

$$\alpha = 0.16(M - m) + 0.0225N,$$

where  $\alpha$  is the alteration of the calorimeter-temperature (*loss of heat*) in millimetres per hour,  $M$  the difference between the average readings of the calorimeter and water-jacket thermometers during the period of observation,  $m$  a small correction (derived from a specially constructed table) to reduce the scale-reading of the second of these thermometers to that of the first, and  $N$  the difference between the average temperature of the calorimeter and that of the air, as indicated by the third outer thermometer and expressed in terms of the scale of the calorimeter-thermometer. Thus, for example, the following table illustrates the observed and calculated values of  $m$ . It is noticeable, *en passant*, that whilst the heating or cooling effect of the air on the calorimeter exerted through the double lid is, for equal differences of temperature, much less than that of the water jacket, it is still not negligible, amounting to about  $\frac{1}{4}$  of that of the jacket.

Water jacket warmer than room. Calorimeter colder than jacket and warmer than room.		Water jacket colder than room. Calorimeter colder than jacket and colder than room.		Water jacket colder than room. Calorimeter slightly warmer than jacket and colder than room.		Water jacket colder than room. Calorimeter warmer than jacket and slightly colder than room.	
Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
-4.8	-4.9	-8.0	-8.2	+0.2	+0.1	+2.3	+2.3
-4.0	-4.1	-7.4	-7.3	-0.2	-0.2	+1.9	+1.9
-3.6	-3.6	-7.0	-6.7	-0.7	-0.6	+1.2	+1.4
-3.2	-2.7	-5.1	-5.4	-1.0	-1.0	+1.0	+1.3
-2.4	-2.0	-4.8	-4.8	-1.5	-1.2	+0.8	+0.8
-1.5	-1.3	-4.3	-4.3	-1.4	-1.2	+0.3	+0.3
-0.9	-0.7	-3.8	-3.9	-1.0	-1.1	+0.2	0
-0.1	0	-3.6	-3.5				
+0.9	+0.7						
+1.2	+1.3						
+1.5	+1.8						
+1.8	+2.1						

42. It is evident from these numbers that the difference between the observed and calculated rates of alteration per hour rarely exceeds 0.2 millimetre, and averages much less; so that the difference between the results deduced by the formula and those attained by direct observation is practically negligible for all experiments lasting for only half an hour or less. In order, however, to diminish any error in the radiation-correction caused by the use of the formula, a threefold determination was made, as follows, the average of the three observations being taken. First, the correction was estimated from the observed average values of M and N throughout the experiment. Secondly, the rate of alteration of temperature of the calorimeter (rising) before the experiment was commenced was determined by observations made for 30–60 minutes before commencing; and, similarly, the rate of alteration (falling) was determined by observations made for 30–60 minutes after concluding, and the mean of the two rates taken. Thirdly, the rate of alteration at the commencement of the experiment was calculated from the values of M and N then observed; and similarly the rate of alteration at the close was calculated from the then values of M and N, and the mean taken as before. The three values rarely differed from their

mean by so much as 0·1 millimetre per hour. Thus the following values were obtained in an experiment lasting eighteen minutes, the + value meaning loss of heat, and the — sign gain\*.

	Millims. per hour.
Value of $x$ obtained by first method (formula applied to mean values of M and N) . . . . .	—1·00
Value of $x$ obtained by second method.	
Observed rate of alteration be- fore experiment commenced . . . . .	—4·1
Observed rate of alteration after experiment concluded . . . . .	+2·0
Value of $x$ obtained by third method.	
Calculated rate of alteration at commencement . . . . .	—4·0
Ditto at close . . . . .	+1·95
	<hr/>
	Average      —1·02

Hence the radiation-correction for the eighteen minutes during which the experiment lasted is  $-\frac{18}{60} \times 1\cdot02 = -0\cdot31$ .

43. The above correction, however, is not the only one to be applied; for the water in the voltameter gets heated more quickly than the calorimeter, and after the end of the experiment some time is required for the heat retained in the voltameter to become uniformly diffused throughout the calorimeter by passage through the glass wall of the voltameter. It was found that 6 or 7 minutes sufficed to bring about perfect equalization of temperature; so that during the first 5 minutes or so the temperature of the calorimeter slightly rose, and then began to fall again from the cooling effect of the radiation. Accordingly, to determine the true amount of rise in temperature during the experiment, the thermometer was read 8, 10, and 12 minutes after the conclusion—the loss by radiation during these several periods of 8, 10, and 12 minutes

\* This particular experiment is selected as an illustration because the temperature-corrections detailed in this and the subsequent paragraphs are larger than those in almost any other of the 18 experiments made in all (§ 46).

being added on to the observed temperature at the ends of these periods severally; the mean of the three numbers thus obtained was taken as the true temperature that would have been observed at the end of the experiment had the heat retained in the voltameter been diffused throughout the calorimeter at that moment. The loss during these three periods is calculated from the data in the latter two methods just described for the determination of the radiation-correction during the experiment: thus, in the illustration given,

		Millims. per hour.
Observed rate of alteration after experiment concluded		+2·0
Calculated	"	+1·95
Mean		+1·97

Hence the losses by radiation during 8, 10, and 12 minutes are respectively, +0·26, +0·33, and +0·39; and the true rise in temperature of the calorimeter is found thus :—

	$t=8.$	$t=10.$	$t=12.$
Reading of calorimeter-thermometer $t$ minutes after conclusion of experiment	201·05	201·0	200·9
Radiation-loss during $t$ minutes	+0·26	+0·33	+0·39
Calculated temperature of calorimeter at close of experiment	201·31	201·33	201·29
Average . . . . .	201·31		

Reading of calorimeter-thermometer at commencement of experiment . . . .	166·7	"
Calculated rise of thermometer . . . .	34·61	"

Correction for radiation during experiment —	0·31	"
Corrected rise of thermometer . . . .	34·30	"

Since the water-equivalent of the calorimeter &c. is 1094·5, and 11·28 millims. of the thermometer-scale represent 1° C., the amount of heat actually produced is

$$\frac{34\cdot30}{11\cdot28} \times 1094\cdot5 = 3328 \text{ gramme-degrees.}$$

44. Two other small corrections also have to be applied to the heat-evolution thus determined. In the first place, the escaping gases pass out saturated with moisture, the evaporation of which absorbs a certain amount of heat. In each experiment the average temperature was close to  $15^{\circ}$ , at which temperature the tension of aqueous vapour is 1.27 centim. or  $\frac{1.27}{76}$  atmosphere, = 1.67 per cent. Hence every 1000 cub. centims. of evolved gas would contain 16.7 cub. centims. of water-vapour (at  $0^{\circ}$  and 760), weighing 0.0134 grammes; the latent heat of water-vapour at  $15^{\circ}$  being nearly 600, this would represent very nearly 8 grammes-degrees per litre of evolved gases. Inasmuch as the gases were evolved not from pure water but from water containing 22 per cent. of sulphuric acid, it is likely that the gases actually evolved contained slightly less moisture than the normal saturating amount; but as in most of the experiments only about 500 to 550 cub. centims. of gases were evolved, the total correction is only about 4 grammes-degrees, and a trifling error in its estimation is negligible.

In the next place a minute amount of heat is absorbed in separating from sulphuric acid the water electrolyzed. From the experiments of Favre and Quaillard (*Comptes Rendus*, l. p. 1150), 98 grammes of sulphuric acid already mixed with 216 of water (forming a dilute acid of composition  $H_2SO_4 + 12H_2O$ ) evolve 483 grammes-degrees when 72 grammes more of water are added (forming  $H_2SO_4 + 16H_2O$ ). The further addition of 72 grammes more of water evolves 222 grammes-degrees, whilst the addition of a third 72 grammes (forming  $H_2SO_4 + 24H_2O$ ) evolves 141 grammes-degrees. From these numbers, by interpolation, it results that acid of strength  $H_2SO_4 + 20H_2O$  (containing 22 per cent. of  $H_2SO_4$ ) will evolve close upon 2.5 grammes-degrees when 1 gramme of water is added to such a quantity of acid as not sensibly to alter its composition by dilution; i. e. that for every gramme of water decomposed by electrolysis 2.5 grammes-degrees are absorbed.

In the experiment the calorimetric details of which have just been given, the corrected heat-evolution finally becomes as follows:—

Heat-evolution calculated from rise of thermometer corrected for radiation &c. . . . .	gramme-degrees.
	} 3328
Correction for heat absorbed by moisture in 0·4967 gramme of mixed oxygen and hydrogen evolved during experiment . . . . .	} 9·2
Correction for heat absorbed in separating 0·4967 gramme of water from dilute sulphuric acid . . . . . . . . . . .	} 1·2
	<hr/> 3338·4

45. The value of E, the average difference of potential between the voltameter plates, was found thus. Before the experiment commenced the scale of the electrometer was standardized by means of a Clarke cell, several readings being taken by reversal so as to obtain total readings each equal to double the deflection; after the experiment was concluded the scale was again similarly standardized. The difference between the two standardizings was always very small or nil, but frequently was just perceptible, owing to leakage of electrometer charge; the mean of the two standardizings was taken to represent a potential difference of

$$1\cdot457 \{1 - (t - 15) \times 0\cdot0006\} \text{ volt,}$$

where  $t$  is the Centigrade temperature, and 0·0006 the alteration in E.M.F. per  $1^\circ$  C. (equal to 0·06 per cent. per  $1^\circ$ ). As in the whole series of experiments taken together the average temperature of the cell was very close to  $15^\circ$ , the cell was assumed to have the constant average value 1·457 volt throughout. Throughout the experiment the potential difference between the electrodes was determined at as nearly as possible equal intervals of time by reversal, the quadrants being connected with the mercury-cups of the voltameter through the reversing-gear. As a general rule, the indicated potential-difference rose steadily throughout the experiment to the extent of from 3 to 6 per cent. of its initial value (owing to polarization of the electrodes); but in some cases this effect was just about compensated by a gradual diminu-

tion in current-strength, so that the potential difference remained nearly the same or slightly fell\*. In the experiment the calorimetric details of which have just been given, the following values were obtained:—

	Scale- divisions.
Value of Clark cell before experiment . . .	80·65
"      "      after                 "      · ·	80·55
Mean . . . . .	80·60

Average of 23 pairs of readings of potential difference between voltameter-plates (commencing with 237·5 and slowly sinking to 231·0)=232·40.

Average potential-difference in volts,

$$\frac{232\cdot40}{80\cdot60} \times 1\cdot457 = 4\cdot201.$$

Hence, taking  $a=8\cdot98$ ,  $\chi=0\cdot000105$ , and  $J=42 \times 10^6$ , the value of  $e$  in the expression

$$e=E - \frac{ha\chi J}{n}$$

becomes  $1\cdot540 \times 10^8$ , since  $E=4\cdot201 \times 10^8$ ,  $h=3338$ , and  $n=0\cdot4967$ .

46. In precisely the same way the following numbers were obtained in seventeen other experiments.

\* The fluctuations in the current and in the potential difference set up between the electrodes necessarily cause corresponding fluctuations in the amount of decomposition per second and the quantity of heat developed per second, and hence are allowed for, and (if not too great in extent) produce no effect at all on the end result. In just the same way, it is immaterial whether the electrodes are perfectly parallel and equal in size, whether the current passes more between their edges than between their centres, of what material they are made, and so on; for what is actually done is to measure the difference of potential between the mercury-cups at the ends of the thick copper rods connected with the electrodes, and also the quantity of electricity passing, and hence the total work done between the cups. The resistance of the cups and thick copper rods being inappreciable, all this work must be done inside the voltameter between the electrodes, either as heat or chemical decomposition; the former being measured directly, the amount of the work representing the latter is known by difference.

Battery-power employed.	Time in minutes.	E. Average difference of potential between electrodes in volts.	n. Grammes of water decomposed.	h. Heat evolved		Value of $\frac{h}{n} \alpha_X J$	Value of $E - \frac{h}{n} \alpha_X J$ .
				Corrected for radiation only.	Further corrected for the other two sources of heat-absorption. (§ 44)		
4 Daniell cells.	44	2.995	.2821	1091	1096	$1.539 \times 10^8$	$1.456 \times 10^8$
4	"	3.065	.2740	1094	1099	1.589 "	1.476 "
4	"	3.134	.2764	1126	1131	1.621 "	1.513 "
5	"	2.4	.3336	.2687	1122	1.227	1.808 "
6	"	2.3	.3380	.2695	1289	1294	1.901 "
6	"	2.2	.3369	.2676	1262	1267	1.875 "
8	"	1.6	.3714	.2785	1543	1548	2.200 "
8	"	1.5	.3685	.2794	1567	1572	2.228 "
8	"	1.4	.3746	.2765	1552	1557	2.230 "
10	"	1.4	.3777	.2708	1553	1558	2.278 "
10	"	1.5	.3845	.2815	1659	1664	2.341 "
12	"	1.3	.3805	.2708	1534	1539	2.250 "
12	"	1.3	.3830	.2729	1606	1611	2.337 "
12	"	1.2	.3979	.2877	1833	1838	2.530 "
12 Daniells and 6 Groves in weak action.	18	4.201	.4967	3328	3338	2.661 "	1.540 "
Ditto .....	17	4.242	.4934	3368	3378	2.711 "	1.531 "
12 Daniells and 6 Groves in full action .....	9.25	4.393	.3379	2479	2484	2.912 "	1.481 "
Ditto .....	8	4.442	.2853	2100	2105	2.921 "	1.521 "
		Average ...		$1.5003 \times 10^8$			

Maximum deviation  
from mean.

$$\text{On side of excess . .} \quad \frac{1.555 - 1.5003}{1.5003} = 3.65 \text{ per cent.}$$

$$\text{On side of deficiency} \quad \frac{1.5003 - 1.449}{1.5003} = 3.42 \quad ,$$

$$\text{"Probable error" of one determination} \pm 0.0202 = \pm 1.34 \quad \text{per cent.}$$

$$\text{"} \quad \text{" result . . .} \quad \pm 0.0048 = \pm 0.32$$

*Experiments on a possible Source of Error in Joule's Valuation of J made in 1867 (Brit. Assoc. Reports).*

47. The method used by Joule in these experiments consisted essentially in the comparison of the resistances of a platinum-silver wire (made into a coil and immersed in a calorimeter) and of copies of the B.A. unit, and then passing a current, measured by a tangent-galvanometer, through the

coil and determining the amount of heat produced therein in a given time. The mean temperature of the calorimeter throughout a series of observations being determined, the resistance which the wire would possess at that temperature was calculated from the observed resistance at some other temperature, the rate of variation in resistance of the wire with temperature used being known. Calling this calculated resistance  $R$ , the average current being  $C$ , and the time  $t$  seconds, the value of  $J$  was deduced by the formula  $J = \frac{C^2 R t}{H}$ , where  $H$  is the heat evolved.

It is evident that any error in the valuation of  $R$  must produce an error to exactly the same extent in the value of  $J$  thus deduced; and that such a source of error must have existed is evident from the circumstance that inasmuch as heat was continuously developed in the interior of the wire, and as an interval of time must necessarily elapse before heat could pass from the interior of the wire into the water by conduction, the temperature of the interior of the wire, and consequently the mean temperature of the wire as a whole, must have been somewhat higher than the mean temperature of the calorimeter. Apart from this, too, the wire must have been heated to a small extent above the whole mass of water in the calorimeter, owing to the adhesion to the wire of a film of warmed water which could not possibly be displaced by stirring absolutely *pari passu* with its becoming warmed. The very efficient automatic continuous stirring-arrangement adopted by Joule in the third series of investigations detailed in the paper referred to must necessarily have reduced this source of superheating of the wire to a minimum; but it is doubtful if it would wholly remove the additional tendency to superheating from this cause.

48. In order to form some idea of the possible extent to which the wire might thus become superheated by currents of the magnitude used by Joule\*, a platinum wire about 50

\* In Joule's experiments the galvanometer made one turn only of 0.62723 foot radius, the angular deflection varying from  $26^\circ$  to  $32^\circ$ ; hence the currents must have lain between  $\frac{0.62723 \times 30.48}{2\pi} \cdot I \cdot \tan 26^\circ$  and  $\frac{0.62723 \times 30.48}{2\pi} \cdot I \cdot \tan 32^\circ$ , where 30.48 is the number of centims. in a

centims. long and 1·15 B.A. unit resistance was twisted into a spiral, the ends of which were soldered to thick copper rods surmounted with mercury-cups and passing through an india-rubber cork to keep them together: this spiral was immersed in a beaker containing about a litre of distilled water, the temperature of which was read off to 0°·1 degree by a thermometer placed with its bulb almost touching the centre of the spiral; by means of a broad horizontal ring of metal attached to a stout wire the water could be briskly agitated, to a much greater extent indeed than would be safe with a calorimeter in which splashing must be avoided. Currents of different strengths were then passed through the coil for periods of time varying from 20 minutes to an hour, a voltameter being also included in the circuit, and the total gas evolved collected as previously described. During this time the water was kept continually stirred, and its temperature observed at equal intervals of time, whilst the difference of potential existing between the ends of the wire was observed as frequently as possible by connecting the mercury-cups with a quadrant-electrometer standardized by a Clark cell before and after the experiment, precisely as above described. During the first two or three minutes the electrometer-readings always diminished through diminution of current by polarization of the voltameter-plates; afterwards they remained nearly constant, gradually rising through the increasing mean temperature of the wire, or slightly sinking if the current-strength diminished through continued use of the battery. During the first few minutes the readings were accordingly taken every 10 or 15 seconds without reversal, so as to obtain a large number of observations giving the mean potential difference during this period; subsequently the readings were taken by reversal at the rate of one pair per minute, the readings being divided into a number of groups corresponding to equal intervals of time (3 or 5 minutes), the average readings for each interval being again averaged to give the mean reading for the whole period;

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foot and I the horizontal terrestrial magnetic force. Taking  $I=0\cdot18$ , the currents must therefore have averaged about 0·3 C.G.S. unit. The resistance of the platinum-silver wire used was nearly equal to 1 B.A. unit =  $10^9$  C.G.S. units.

so that for an hour's observation more than 120 total readings were taken.

49. In this way the following numbers were obtained, the amounts of gas collected being translated into C.G.S. current-units by the formula

$$C = \frac{V \times 0.0005363}{T \times 60 \times 8.98 \times 0.000105} = \frac{V}{T} \times 0.09479,$$

where  $C$  is the C.G.S. current,  $V$  the volume of gas (dry, at  $0^\circ$  and 760 millims.),  $T$  the time in minutes, and 0.0005363 the weight in grammes of a cubic centim. of mixed gases at  $0^\circ$  and 760 ( $\S$  39); *i. e.* where  $\frac{V}{T}$  is the volume of gas evolved per minute. The resistance of the wire is calculated from Ohm's law ( $C = \frac{E}{R}$ , whence  $R = \frac{E}{C}$ ) by dividing the average potential difference by the current. Every experiment was made as nearly as possible in the same way, so as to diminish sources of error and make the results comparable, the only noteworthy difference being that with the stronger currents shorter times were given, and the beaker of water in which the wire was immersed was slightly cooled at intervals during the experiment to avoid the temperature rising too high and having too wide a range.

No. of cells in battery.	Time in minutes.	Gas evolved in cub. cent., dry at $0^\circ$ and 760 mm.	Average G.C.S. current.	Temperature of water.			Average potential-difference in C.G.S. units.	Resistance in C.G.S. units.
				Initial.	Final.	Average.		
3	60	256.6	0.0406	8.5	10.0	9.24	$0.4655 \times 10^8$	$1.147 \times 10^9$
		234.5	0.0371	7.5	9.5	8.36	0.4275 "	1.152 "
	Average	245.5	0.03885	.....	.....	8.80	.....	1.1495 "
4	30	244.3	0.0772	7.9	9.2	8.50	0.8931 "	1.157
6	30	461.7	0.1459	7.4	9.0	8.20	1.697 "	1.163 "
9	30	777.9	0.2458	7.2	11.0	9.16	2.881 "	1.171 "
		493.4	0.2339	7.4	9.7	8.58	2.732 "	1.168 "
	Average	635.65	0.2398	.....	.....	8.87	.....	1.1695 "
12	20	624.7	0.2961	7.1	10.1	8.64	3.469 "	1.172 "
		638.6	0.3027	7.6	10.8	9.18	3.549 "	1.172 "
	Average	631.65	0.2994	.....	.....	8.91	.....	1.172 "

Since the average temperature of the water surrounding the wire was nearly the same throughout, not differing by more than a few tenths of a degree from the mean  $8^{\circ}75$ , the values in the last column are fairly comparable with one another; whence it is evident that a notable rise in resistance of the wire is produced by each successive increase in current-strength. The resistance of the wire for a current of very small value would clearly lie under  $1\cdot1495 \times 10^9$ ; so that the increase in resistance caused by currents of from 0·24 to 0·30

C.G.S. unit is at least  $\frac{1\cdot1695 - 1\cdot1495}{1\cdot1495}$  to  $\frac{1\cdot172 - 1\cdot1495}{1\cdot1495}$ , or 1·7 to 2·0 per cent.

50. In order to see what increase in mean temperature of the wire over that of the surrounding water this would represent, the fourth experiment was repeated, using warm water (at about  $27^{\circ}$ ) to surround the coil: in this way the following numbers were obtained:—

	C.G.S. current.	Average temperature.	Potential- difference.	Resistance.
Water warmed .	0·1419	$27\cdot25$	$1\cdot716 \times 10^8$	$1\cdot209 \times 10^9$
„ cold . .	0·1459	8·20	$1\cdot697 \times 10^8$	$1\cdot163 \times 10^9$
Difference .		19·05		$0\cdot046 \times 10^9$

Since an increase in resistance of 0·046 corresponds to 19·05 degrees, an increase of 0·0200 to 0·0225 would correspond to 8·3 to 9·3 degrees; *i.e.* currents of 0·24 to 0·30 C.G.S. unit caused a superheating of the wire above the temperature of the surrounding water to an extent averaging  $8\cdot3$  to  $9\cdot3$ \*. If it be admitted that in Joule's experiments a similar superheating to the extent of  $8^{\circ}$  to  $9^{\circ}$  may have taken place, the effect on the calculated resistance of the platinum-silver used would be to cause the amount to be underestimated by about  $8 \times 0\cdot031 = 0\cdot25$  per cent. to  $9 \times 0\cdot031 = 0\cdot28$  per cent., 0·031 being the percentage increase in resistance per degree of the alloy used by Joule (this alloy was purposely not used by the authors,

\* This increase in resistance with temperature amounts to about 0·21 per cent. per  $1^{\circ}$  C. Matthiessen found the average increase of pure metals to be about 0·37 per cent. per  $1^{\circ}$  C., that of an alloy of platinum and iridium containing 33 per cent. of the latter being only 0·06 per cent. per  $1^{\circ}$ ; probably, therefore, this platinum wire was somewhat impure, very likely containing iridium.

in order to make the alteration in resistance, if any, more perceptible); that is, the value of  $J$  ultimately deduced would be about 0.25 to 0.28 per cent. too low.

51. In order to see whether an increased amount of super-heating would be produced by only stirring the water surrounding the wire at intervals of one or two minutes instead of continuously, some of the above observations were repeated under these conditions with the following results, clearly showing that whilst no very material influence is exerted by discontinuous stirring with weak currents, the effect is marked with currents of 0.23 to 0.29 C.G.S. unit.

Cells in battery.	Average temperature.	Average current.	Potential-difference, in volts.	Resistance	
				at average temperature of experiment.	corrected to 8°75.
3	7.75	0.03155	0.3628	$1.150 \times 10^9$	$1.152 \times 10^9$
6	7.25	0.1350	1.562	1.157 "	1.160 "
9	8.30	0.2285	2.717	1.189 "	1.190 "
12	7.70	0.2880	3.441	1.195 "	1.197 "

52. In order to see whether any analogous effect would be produced by varnishing the wire, as was done in Joule's experiments (owing to possible diminution in rate of passage of heat from wire to water through diminished conducting-power of the varnish), a thin coat of clear filtered shell-lac varnish was lightly applied to the wire; and after two days drying, some of the observations were repeated, with the result of showing that whilst the effect of the varnishing was inappreciable with a weak current, it became noticeable with currents of 0.14 to 0.24 C.G.S. unit. To make sure that the resistance of the wire itself had not been altered permanently by strain &c. during varnishing, the varnish was dissolved off by immersion in alcohol, after which the resistance-value again diminished to its former amount. Thus the following numbers were obtained:—

	Current.	Cells used.	Mean temperature.	Potential-difference.	Resistance.
After varnishing .....	0·0808	4	8·85	$0·9347 \times 10^8$	$1·157 \times 10^9$
Before " (suprà)	0·0772	4	8·50	0·8931 "	1·157 "
			Increase in resistance ...		Nil.
After varnishing .....	0·1426	6	8·79	1·675 "	1·174 "
Before " .....	0·1459	6	8·20	1·697 "	1·163 "
			Increase in resistance ...		0·011 "
After varnishing .....	0·2273	9	8·93	2·676 "	1·178 "
Before " .....	0·2398	9	8·87	2·806 "	1·169 "
			Increase in resistance ...		0·009 "
After varnish again dissolved off .....	0·2426	9	8·75	2·835 "	1·168 "

Apparently, therefore, with the stronger currents the varnish produced an increase in resistance about equal to that due to an increase in temperature of from  $4^\circ$  to  $5^\circ$ ; so that if the varnish in Joule's experiments produced a similar effect, the total superheating must have been near  $12^\circ$  to  $14^\circ$ , representing 0·37 to 0·43 per cent. of error in deficiency in the estimation of R, and consequently of J.

53. Yet another source of error, and in the same direction, in these experiments of Joule's lies in the fact that, in comparing the resistances of the B.A. unit and the experimental wire employed, the method adopted consisted in determining the angular deflections  $\alpha$ ,  $\beta$ , and  $\gamma$  produced in a tangent-galvanometer on passing the current from a given electromotor (1) through the galvanometer only, (2) through the galvanometer and B.A.-unit coil, and (3) through the galvanometer and experimental wire—the resistance of the experimental wire being called  $x$ , and that of the unit coil = 1,

$$x = \frac{(\tan \alpha - \tan \gamma) \tan \beta}{(\tan \alpha - \tan \beta) \tan \gamma}.$$

Now, were the currents used so feeble that no appreciable amount of heat was developed by them in either wire, or were the two wires compared similarly sized and situated so as to be heated to equal extents, the value of  $x$  thus deduced would be subject to no other errors than the instrumental and obser-

vational ones ; but as the B.A.-unit-coil wires are imbedded in solid paraffin whilst the experimental wire was immersed naked in water (save for the film of varnish), it is evident that, if any heat at all had been generated by the currents employed, the B.A.-unit coil must have been more heated than the experimental wire, as the heat developed could not pass away readily through the badly conducting solid paraffin. The currents actually employed were sufficient to cause deflections of  $36^\circ$  to  $37^\circ$  with a galvanometer of nine turns and 17 inches diameter, and of  $34^\circ$  to  $50^\circ$  with a galvanometer of eighteen turns and 17 inches diameter ; so that the currents were of magnitude equal to from

$$\frac{17 \times 2.54}{4\pi \times 18} \cdot I \tan 34 \text{ to } \frac{17 \times 2.54}{4\pi \times 9} \times I \tan 37$$

(where  $I$  is the horizontal magnetic terrestrial force =  $0.18$ , and  $2.54$  is the number of centims. in an inch), or averaged about  $0.04$  C.G.S. unit. In a wire of 1 B.A. unit resistance a current of this magnitude would produce per minute  $\frac{0.04 \times 0.04 \times 10^9 \times 60}{42 \times 10^6} = 2.3$  gramme-degrees, which, assuming the wire to weigh 10 grammes and to have the specific heat  $0.04$  (approximately that of an alloy of one part silver to two of platinum), would raise its temperature  $\frac{2.3}{10 \times 0.04}$ , or nearly  $6^\circ$  per minute.

It would therefore seem from this rough estimate that the heat-development produced in the B.A.-unit coil by the currents used may have been sufficient to raise its temperature perceptibly above that attributed to it ; while the same result would not be produced to any thing like the same extent with the experimental wire, owing to the latter being immersed in water instead of solid paraffin. If it be assumed that this heat-development sufficed to raise the average temperature of the B.A.-unit coil during the observations  $5^\circ$  above that of the experimental wire (an amount of heating not at all unlikely to have occurred), the ultimate effect of this would be to cause the underestimation of  $R$ , and consequently of  $J$ , by  $5 \times 0.031 = 0.15$  per cent.

54. Hence, finally, putting together this source of error and that due to the superheating of the wire (increased by varnish-

ing), there is reason for supposing that the value of  $J$  obtained by Joule in 1867 by the electric-current method may be at least 0·5 per cent. too small; that is, instead of giving a value 1·31 per cent. larger than that deduced from Joule's water-friction experiments of 1850 and 1878 (Part I. § 34), the corrected value would probably be at least 1·8 per cent. larger than the water-friction value.

The practical conclusion to be drawn from these experiments, then, is that, in any determination in which it is necessary to pass a current through a wire for any length of time, an appreciable error, through increase in the resistance of the wire, will be brought about by its becoming superheated above the temperature of the medium in which it is placed when the current exceeds a certain limit, the exact value of which necessarily depends on the conditions. This source of error will affect determinations of E.M.F. made by such methods as those used by Latimer Clark in the valuation of his standard cell (Proc. Roy. Soc. xx. p. 444), and will similarly affect any experiments on the determination of  $J$  by methods based on the same principles as those involved in Joule's 1867 observations, unless the mode of experimenting be modified in such a way as to eliminate this source of error, or at least to render it negligible. We propose to examine certain such modifications which have occurred to us as being likely to reduce this source of error to an inconsiderable amount.

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**XXX. Determination of the Acceleration of Gravity for Tokio, Japan. By W. E. AYRTON and JOHN PERRY.**

As no experiments had, as far as we were aware, been made to determine the value of  $g$  in Japan, it appeared to us desirable that the value should be accurately measured, at any rate for our own college in the capital, Tokio. Consequently in 1877 an elaborate series of experiments was carried out by some of the students under our supervision. The method first employed consisted in experimentally finding two parallel axes in a pendulum on opposite sides of the centre of gravity, and in a plane with it, such that the times of oscillation about either axis would be the same. The distance, then, between

these axes experimentally found would, as is well known, be the length of the equivalent simple pendulum, from which  $g$  could be calculated by the formula

$$t = \pi \sqrt{\frac{l}{g}}$$

Two Kater's pendulums were employed—one made by Messrs. Elliott, and the other by Messrs. Negretti and Zambra. Borda's method of coincidence was employed; that is, one of the Kater's pendulums was suspended exactly in front of the pendulum of a clock, consisting of a wooden rod carrying a brass bob and beating approximately seconds. One observer watched the two pendulums, vibrating one in front of the other, through a telescope some ten feet away; and at the instant a pointer attached to one of the pendulums exactly coincided with a line drawn on the other (the coincidence taking place in the axis of the telescope as observed by the cross-wires), a signal was given, and the time of the clock noted by two independent observers. A very large number of successive coincidences was in this way observed, then the Kater's pendulum inverted, swung on the other knife-edge, and the same thing repeated. From these experiments the exact time of vibration of the Kater's pendulum about either knife-edge was ascertained, and one or both knife-edges moved to diminish the difference in the time of vibration, and the whole experiment repeated.

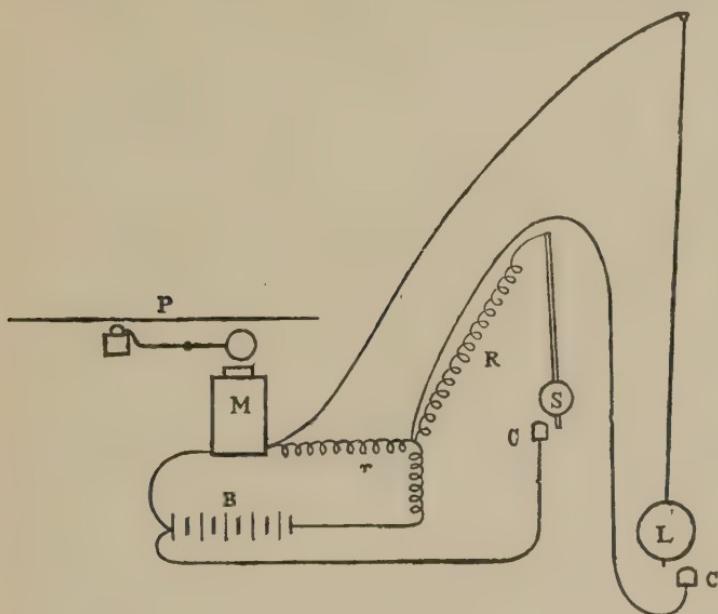
But although these observations, first with one of the Kater's pendulums and then with the other, were continued for some months, many thousands of vibrations being observed by the students, who worked at these experiments in their usual most praiseworthy way, the results were always unsatisfactory. For an approximate value of  $g$  for any part of the earth's surface can be calculated by a formula developed by Clairault, who from pendulum-experiments made at a variety of latitudes on the earth's surface has shown that, approximately, for any latitude  $\lambda$  and any height  $h$  centimetres above the level of the sea,

$$g = 980.6056 - 2.5028 \cos \lambda - 0.000003h.$$

As the latitude of the Imperial College of Engineering, Tokio, is about  $35^\circ 39'$ , Clairault's formula gives for  $g$  the

value 979·7 centimetres per second per second. But the value obtained by the series of experiments made with the Kater's pendulums differed too much from this and from one another to allow of our trusting them.

We therefore decided on employing a totally different method and a much less laborious one:—A brass ball 2352·2 grammes in weight was suspended by a long steel wire 0·45 millimetre in thickness, and in the earlier experiments 978·7 centimetres in length. The wire was supported from a steel knife-edge resting on a brass plate. Both the brass ball and the bob of the seconds-pendulum of the standard clock were fitted with fine pieces of platinum wire, either of which dipped into a small cup of mercury when the pendulum to which it was attached was vertical. The mercury-cups &c. were then joined up with a battery and resistance-coils to a quick-running Morse instrument, as seen in the figure, in which M is



the Morse instrument, B the battery, P the paper, S the seconds-pendulum, L the long pendulum, C, C the mercury-cups, R a resistance small compared with that of M plus that of the coil  $r$ , but large compared with that of M alone. The whole constituted what is known as a "break-circuit chrono-

graph;" that is, a continuous ink mark was made on the paper run out by clockwork, broken by a very small gap each time the wire attached to the bob of the seconds-pendulum passed through the mercury. These breaks, then, in the ink line indicated seconds; if, however, both pendulums were simultaneously in the vertical line, no break was made. Hence the absence of a break in the line at the end of any special second indicated coincidence of the two pendulums; and in this way the times of a large number of coincidences could be automatically registered.

During this set of experiments we could not measure the length of the long fine steel wire with as much accuracy as was desired, since, although we had two or three brass scales, the makers had omitted to record on them at what temperatures they were correct. However, assuming that one of them was accurate at  $0^{\circ}$  C., then a rather large number of experiments gave, as the value of  $g$ , 978.8 centimetres per second as a first rough approximation.

Subsequently we obtained from the Finance Department of Japan the loan of two very beautiful standard brass scales, by Deleuil of Paris, and guaranteed correct at  $0^{\circ}$  C. One was graduated in millimetres; the other consisted of a brass rod with two pieces at its ends at right angles to the rod, and the distance between the two planes of the inner surfaces of the pieces was exactly a metre at  $0^{\circ}$  C. We now had, then, the means of making a far more complete series of experiments than before; but as our trial pendulum was nearly ten times as long as the seconds-pendulum of our clock, the method of coincidences was an inconvenient one; and so we merely adopted the following:—The long pendulum alone controlled the "break-circuit chronograph;" so that the number of breaks in the line during any time indicated the number of vibrations of the long pendulum in that time. At the commencement of the experiment, after the pendulum had been set swinging and the paper was running out at a fairly uniform speed, a mark was made on it by tapping sharply the armature up with the finger when a chronometer, lying beside the Morse instrument, indicated a certain time; and after an hour or so, the paper being kept running all the time, a second mark was sharply made on the paper when the chronometer indicated a

certain other noted time. So much paper had then run out in the interval of time shown by the chronometer; and the breaks in the line, counted carefully afterwards by two independent students, gave the whole number of vibrations of the pendulum in that time. The fraction of a vibration could also, of course, be ascertained by comparing with the length of the lines in the neighbourhood the length of the first line made after the first break had been produced, on tapping the armature, and repeating the same process at the end of the paper. The experiment is, of course, independent of the rate at which the paper runs out, provided, of course, it is never allowed to run so slowly that there is any difficulty in distinguishing the different breaks electrically made by the long vibrating pendulum. The mean temperature of the wire was carefully taken at each experiment. A sample of one or two of the many experiments recorded in the students' laboratory notebook follows.

*Number of Experiment 26.—25th of January, 1878.*

Number of vibrations obtained from counting } 1015½
on the paper . . . . .
Time taken—observed on the chronometer . 0 h. 52 m. 0 s.
Mean temperature at the beginning . . . . . 10°·5 C.
" " " end . . . . . 11°·25 C.
Time of vibration = 3·0744 seconds.

*Number of Experiment 45.—15th of February, 1878.*

Number of vibrations obtained from counting } 1385·5
on the paper . . . . .
Time taken—observed on the chronometer . 1 h. 11 m. 0 s.
Mean temperature at the beginning . . . . . 9°·25 C.
" " " end . . . . . 12°·25 C.
Time of a vibration = 3·0745 seconds.

*Number of Experiment 53.—21st of February, 1878.*

Number of vibrations obtained from counting } 1288·5
on the paper . . . . .
Time taken—observed on the chronometer . 1 h. 6 m. 0 s.
Mean temperature at the beginning . . . . . 8°·5 C.
" " " end . . . . . 12°·25 C.
Time of a vibration = 3·0741 seconds.

Frequent sun-observations were made to check the rate of the chronometer, which is comparatively easy in Japan, as during the winter there the sun is seen almost daily from sunrise to sunset.

The next point was to measure accurately the length of the wire. As it was impossible to do this satisfactorily with the wire hanging up, it was taken down without disconnecting either the knife-edge carrying it or the ball at the other end. The knife-edge was then fixed at one end of a horizontal rail, and the other end of the wire close to the ball hung over a wheel with very little friction. By this arrangement the wire in a horizontal position was, of course, stretched as much as it was in the vertical position, as far as the effect of the weight of the ball was concerned. A correction had, however, to be made for the weight of the wire itself, which of course caused the tension to be a little less at the bottom than at the top when the pendulum was hanging up vertically. A few centimetres of similar fine steel wire being weighed, a simple integration gave the small additional weight necessary to be added. This being done, the final result obtained was that the length of the pendulum equalled 939.09 centimetres at 0° C.; and the consequent value of  $g$  in air for Tokio, Japan, calculated from the result of about eighty thousand vibrations of the long pendulum, would be 980.06 centimetres per second per second, if the pendulum could be regarded as a simple mathematical pendulum.

#### *Correcting Factors.*

1. The two most obvious corrections to apply to this result are the corrections for infinitely small arcs and for the air-friction—neither of which were found of any practical consequence, on account of the very small angle through which the pendulum usually swung, and that the decrement of the amplitude of the vibrations was imperceptible even after many swings. Although, however, such a pendulum as we were using approaches very nearly a perfect simple pendulum, there are certain causes of possible error arising from its flexibility and slight elasticity which would not affect a rigid compound pendulum. To estimate the practical effect of these possible errors, it is necessary to solve generally the complete problem

of a heavy ball supported by an elastic wire, one end of which is soldered to the ball and the other end to a steel knife-edge. When a suspended ball is swinging in the arc of a circle, we know that near the end of a swing the attachments of the ball have to resist a tendency for the ball to turn. For since the ball has been turned in passing from its lowest to its highest position, it would continue to turn were it not stopped by the wire itself. At the end of every swing, then, there must be a slight kick ; so that in fact the ball will make minor swings about its point of attachment all the time of the motion. To make this kick less perceptible, we must make the fastening of the wire to the ball capable of resisting the tendency of the ball to continue its turning motion. If we do this by soldering the wire, a smaller kick will result, and will be due to the bending-moment of the wire resisting the turning action. If there were no difficulty of construction, it might be better to get rid of this kick difficulty by making the bob capable of rotating in the plane of swinging about an axis through its centre of gravity.

The investigation of the general problem of the swinging of a heavy ball soldered to an elastic wire, the upper end of which is attached to a knife-edge, may take somewhat the following form:—Let A be a ball, of mass  $m$  and radius  $a$ , suspended from a free hinge at B by a chain of  $n-1$  links, each of length  $a$  and hinged to one another, the last hinge being on the surface of the ball. Suppose at any hinge where two adjacent links make an angle  $\theta$  with one another, equal and opposite couples act in them of moment  $c\theta$  tending to bring them into the same straight line. As  $n$  is made greater and greater, we approximate more and more nearly to our actual case of an elastic wire. Let  $n$  be very great, and  $\phi_1, \phi_2, \dots, \phi_{n-1}$  the inclinations of the 1st, 2nd,  $\dots$  ( $n-1$ )th link to the vertical, the  $n$ th link being the radius of the ball up to the hinge, and its inclination  $\phi_n$ . If now we know the mass of the links per unit of length, it is easy to state the values of  $\psi_1, \psi_2, \dots, \psi_s, \dots, \psi_n$ , the couples acting on each respective link : thus

$$\psi_n = mga \sin \phi_n + c(\phi_n - \phi_{n-1}),$$

care being taken to remember that the form of  $\psi_s$  is different from that of  $\psi_1$  or of  $\psi_n$ .

If the inclination  $\phi$  is everywhere very small, we find, if  $v_s$  is the velocity of the end of link  $s$ , that

$$v_s^2 = a^2 \{ (\dot{\phi}_1)^2 + 2\dot{\phi}_1\dot{\phi}_s \cos(\phi_s - \phi_1) + (2s-3)(\dot{\phi}_s)^2 \},$$

where  $\dot{\phi}_s$  means  $\frac{d\phi_s}{dt}$ .

So that the kinetic energy  $T$  of the whole system may at once be written out in terms of the coordinates  $\phi_1, \phi_2, \dots$  &c.,  $\dot{\phi}_1, \dot{\phi}_2, \dots$  &c.

We can therefore find the partial differential coefficients

$$\frac{dT}{d\dot{\phi}_1}, \quad \frac{dT}{d\dot{\phi}_2}, \text{ &c., and } \frac{dT}{d\phi_1}, \quad \frac{dT}{d\phi_2}, \dots \text{ &c.,}$$

so as to use Lagrange's equation

$$\frac{d}{dt} \left( \frac{dT}{d\dot{\phi}} \right) - \frac{dT}{d\phi} = -\psi.$$

In this way we have obtained the  $n$  differential equations connecting  $\phi_1, \phi_2, \dots \phi_n$ , and their first and second differential coefficients with respect to  $t$ . As, however, these equations can only be regarded as true when  $n$  is infinite, and as the labour of solution is very great when  $n$  is great, it seems useless proceeding further with the solution.

If we regard the motion of the ball as a harmonic motion of period  $P$ , determined by assuming the connexions as rigid, combined with motions of much shorter periods  $P_1, P_2, P_3, \dots$  &c., there will be some little difficulty in finding the motion of shortest period  $P_1$ , namely the *kick* above mentioned; but we know that when the wire is, as in our experiments, very thin, the kick cannot be much less than the time of a complete vibration of the ball when freely suspended by a point on its surface, or

$$2\pi \sqrt{\frac{12a}{5g}},$$

where  $a$  is the radius of the ball. But this periodic time is 0.528 seconds, or about one twelfth of that of the pendulum moving as a whole, which is about 6 seconds.

Since the tendency of the ball to add this quick vibration to its motion is due to its rotational energy, it may be diminished by lessening the moment of inertia of the ball (that is, by making the ball small), or by diminishing the angular velocity

of the pendulum (that is, by making the pendulum as long and its swing as small as possible). We may regard, then, the motion of the ball as compounded of a pure harmonic motion with an amplitude of about 30 centimetres and a periodic time of 6 seconds, with another motion having a very small amplitude and with a period of about half a second. But we have proved in the paper on our seismograph\*, that in such a case the compound motion would differ very slightly from that of a pure harmonic motion, even if there were no internal friction in the substance of the wire (supposing the pendulum started without shock); but as internal friction, of course, exists in the wire, this error becomes exceedingly small.

2. Next, with regard to the stretching of the wire arising from variations in the centrifugal force of the ball while swinging. Since the time of a complete vibration of our pendulum was nearly 6 seconds and the arc about 30 centimetres, the velocity at the middle of its path was

$$\frac{30 \times \pi}{6}, \text{ or } 15.7 \text{ centimetres per second;}$$

hence the pull on the wire, which at the end of the swing was equal to the weight of the wire, or 2352.2 grammes, was increased by

$$\frac{2352.2 \times (15.7)^2}{939 \times 979.7} \text{ grammes}$$

at the middle of the swing. But this is less than a gramme, so that no practical extension of the wire arose from centrifugal force.

3. Shortening of the length of the wire, due to its curvature, arising from the resistance of the air making it concave in the direction of motion. It is easy to see that the shortening of the pendulum due to this cause is excessively small, and is of the same order as the lengthening arising from the centrifugal force; so that these two very small errors may be regarded as balancing one another.

Also, since it may be calculated that the period of transverse vibration of the wire is less than one fortieth of the periodic

\* "On a Neglected Principle that may be employed in Earthquake Measurements," Trans. Asiatic Soc. of Japan, vol. v. part 1, p. 181; reprinted in Phil. Mag. July 1879.

time of the pendulum, the resistance of the air cannot tend to cause amplification of the lateral vibrations in the wire itself.

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We may therefore assume that our pendulum vibrated like a rigid body, consisting of a ball of brass, a straight steel wire, and a triangular steel prism of which the edge was the fixed axis.

### *Calculation of g.*

The complete formula is, of course,

$$t = \pi \sqrt{\frac{\Sigma(mr^2)}{l \cdot mg}},$$

$l$  being the distance from the axis of rotation to the centre of gravity of the pendulum.

The steel knife-edge had a length of about 4 centimetres, a breadth of about 1 centimetre, and a depth of  $\frac{1}{2}$  a centimetre; hence its weight was about 7.8 grammes, its moment of inertia about the axis of rotation  $0.98$  (gramme, centimetre), and the distance of its centre of gravity from the axis of rotation 0.33 centimetre. The weight of the wire was 11.6 grammes, and its length 934.99 centimetres at  $0^\circ$  C. Its moment of inertia was therefore  $3.3803 \times 10^6$  (gramme, centimetre), and the distance of its centre of gravity from the axis of rotation 467.49 centimetres. The weight of the brass ball was 2352.2 grammes, its moment of inertia about the axis of rotation  $2.0744 \times 10^9$ , and the distance of its centre of gravity 939.09 centimetres at  $0^\circ$  C. Of the whole system, then, the weight was 2371.6 grammes, the moment of inertia about the axis of rotation  $2.0778 \times 10^9$  (gramme, centimetre), and the distance of its centre of gravity  $2.2144 \times 10^6$ . Consequently

$$g = \left(\frac{\pi}{t}\right)^2 \frac{2.0778 \times 10^9}{2.2144 \times 10^6},$$

and

$$t = 3.0748 \text{ seconds};$$

or

$$g = 979.58 \text{ centimetres per second per second in air},$$

or

$$g = 979.74 \text{ centimetres per second per second in vacuo} \\ \text{for the Imperial College of Engineering, Japan—}$$

a result agreeing extremely closely with the number 979.7 obtained above from Clairault's formula.

In beginning this series of observations we expected to find  $g$  to be greater than what Clairault's formula gives it. Our reason was this:—Clairault's formula assumes a circular equator; Capt. Clarke has found that the equator is elliptical, one extremity of its major axis being in  $15^{\circ} 34' E.$  longitude; and therefore Tokio is in longitude nearer a minor axis than a major one. We find, however, a reason why  $g$  satisfies so well Clairault's formula, in spite of this eccentricity of the equator. The greatest depression of the earth's surface is only a few hundred miles to the east of Japan; and probably the diminution in  $g$  produced by this cause just counterbalances the increase of  $g$  produced by ellipticity of the equator. As for local perturbations, it is to be remarked that Tokio is situated on a very large plane, there being no hills of any magnitude within eighty miles. We think that the geodesy of Japan is of special interest on account of the great Pacific depression, and on account of the very gradual slope of the earth's surface from Japan to China, which causes Japan to be a sort of ridge.

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Probably the best method of determining the value of  $g$  would be to use a *rigid* homogeneous pendulum, of such a shape that its moment of inertia could be easily calculated with accuracy from its linear dimensions measured at any temperature—for example, a sphere at the end of a cylindrical rod with a knife-edge, all cast in one piece and turned true in the lathe, or a cylindrical bob cast at the end of the cylindrical rod. The only possible objection to this method would be the possible want of homogeneity in the metal. This might be allowed for in the following way:—Instead of casting the cylindrical bob in one piece, make it consist of a number of concentric tightly fitting cylindrical shells accurately turned. Experiments would then be made first with the cylinders all in one position, then with some of them twisted slightly round, and so on until in the mean result the errors of eccentricity of mass would probably be eliminated.

Another, and perhaps the best of all methods, would be for

rigid compound pendulums to be accurately timed experimentally at Greenwich at a number of different temperatures, and sold with a scale of temperature-corrections for the time of vibration attached.

One set of experiments, then, with one of these pendulums anywhere would at once give the value of  $g$ ; and such a pendulum would undoubtedly be the most suitable for surveys and expeditions in foreign countries. The fact is, the mathematical beauty of the principle involved in the Kater's pendulum has, in our opinion, caused far too much importance to be attached to it as a practical instrument for determining experimentally the value of the acceleration of gravity.

We have to thank several of our late students, and especially Messrs. Honda, Kikkawa, A. Kasai, J. Nakahara, and H. Nobechi for assistance rendered us during this investigation. And it may here be mentioned that this investigation, like the many others we have been enabled to carry out during the last few years, has resulted from the plan we have followed of teaching the laboratory students not, as is customary in Colleges, to repeat well-known experiments, but to endeavour in their investigations to advance, in some small degree at any rate, the bounds of existing knowledge. And this system of enlisting the assistance of even quite young students in original research we have found to create an enthusiasm in experimental work otherwise unproducible.

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### XXXI. *On Induction in Telephonic Circuits.* By W. GRANT\*.

THE apparatus used in the following experiments was such as was ready to hand in the laboratory. The particulars given are intended merely to show the conditions under which the results described were obtained; there is no reason to suppose that moderate, or perhaps even considerable alterations in the dimensions of the apparatus would have caused the results to be essentially different.

One of the appliances used is a coil which consists of two similar No. 20 copper wires of equal length wound side by side throughout, forming a coil of 2·3 centimetres internal,

\* Read January 24th, 1880.

and 12·7 centimetres external diameter, and about 12·5 centimetres in length. The resistance of the two wires connected end to end is 28 ohms. This is afterwards referred to as the double helix.

Two other coils, afterwards spoken of as "flat" coils, consist of approximately equal lengths of No. 19 copper wire, wound in rectangular grooves in two flat wooden reels. The inside and outside diameters of these coils are about 10 centimetres and 15 centimetres respectively. The resistance of each is roughly 1 ohm.

Two rough coils of copper wire, in the state in which they came from the manufacturer, were also employed in the first experiment described ; but as they are not afterwards referred to, their dimensions need not be given.

If four separate circuits are so arranged that the primary one includes a battery, a microphone which is actuated by a watch, a telephone, and one of the wires of the double helix—the secondary includes the other wire of the double helix, a telephone, and a rough coil—the tertiary includes another rough coil in proximity to that in the secondary circuit, a telephone, and a flat coil—the quaternary includes another flat coil in proximity to that in the tertiary circuit, and also a telephone,—a current of a different order circulates in each of the separate circuits, and the following effects are observed.

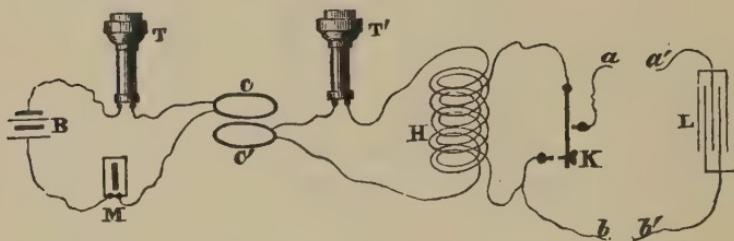
The loudness of the sounds in the telephones in the primary and secondary circuits is as nearly as possible the same, in fact no difference can be detected between them ; but in the tertiary and quaternary circuits the sounds are not so loud, partly no doubt because the mutual induction between the secondary and tertiary circuits, and between the tertiary and quaternary, was less than that between the primary and secondary, seeing that the coils by whose mutual induction the effects were transferred from the secondary to the tertiary circuit, and from the tertiary to the quaternary, were wound separately, and consisted of a smaller length of wire than the two which were wound side by side to form the double helix used to transfer the induction from the primary to the secondary circuit.

The pitch of the sound, however, is found to be the same in all the four circuits. Now, if the rate of the pulsations of

induced currents is greater as the order of the current is higher, and if the telephone is capable of vibrating in unison with these pulsations, it follows that the pitch of the sound should be higher in some of the telephones than it is in others. But as the pitch of the sound is the same in all, either the telephones do not vibrate in unison with the rapid pulsations of the currents of high order, or the sameness of pitch must be due to some other cause.

The arrangement of apparatus in the next experiment is shown in fig. 1.

Fig. 1.



There are three separate circuits. The primary includes a battery B, a telephone T, a flat coil C, and a microphone M; the secondary includes a flat coil C', a telephone T', and one of the wires of the double helix H; the tertiary includes the other wire of the double helix and a contact-key K. L is a condenser.

The coils C and C' are placed with their faces in contact and their axes coincident; and the microphone is actuated by a watch.

When a battery-current circulates in the primary circuit under these circumstances, currents are induced in the secondary and tertiary circuits, and it is observed, when the ear is applied to the telephone in the secondary circuit, that the loudness of the sound is increased when the key is depressed and the tertiary circuit is closed, and that it again becomes weak when the key is raised and the tertiary circuit is opened. The increase in the loudness is most readily observed when the sound is rather faint when the tertiary circuit is open; for if the sound is already loud the increase is not so marked.

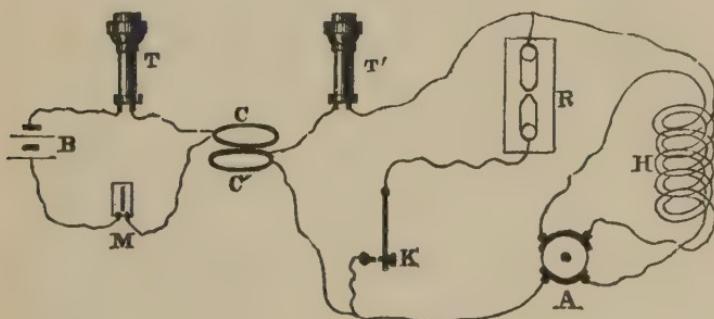
The increased loudness seems to be due to an increase in the strength of the secondary current, caused by the reaction

upon it of the currents induced in the tertiary circuit when the key is depressed. When the tertiary circuit is open, the self-induction of the secondary circuit opposes the variations of the secondary current; but when the tertiary circuit is closed, the mutual induction between it and the secondary circuit neutralizes to a great extent the effect of the self-induction of the secondary current, the strength of which is increased or augmented by the inverse currents in the secondary circuit, due to the reaction of the tertiary current upon it.

If the condenser L, fig. 1, is connected to the tertiary circuit by joining the wires at  $a\ a'$ , and  $b\ b'$ , it will be brought into action when the key is raised, and short-circuited when the key is depressed. If its capacity is three quarters or half a microfarad, the sound in the telephone  $T'$  retains its normal pitch when the key is depressed; but when the key is raised and the condenser is brought into action the pitch of the sound rises; and the rise is greater with half than with three quarters of a microfarad. With a capacity of from about one to five microfarads, the sound retains its normal pitch.

The arrangement for the following experiment will be intelligible from fig. 2.

Fig. 2.



The primary circuit is the same as that in fig. 1, where B, T, C, and M, represent the battery, telephone, coil, and microphone respectively. The secondary circuit includes the coil C', the telephone T', the double helix H, and a commutator A, by means of which the direction of the current can be reversed in one of the wires of the helix. K is a key which, when it is depressed, short-circuits the double helix; R is a box of resistance-coils.

If the commutator is so placed as to cause the current to pass through both wires of the double helix in the same direction, the self-induction is strong, the current is weakened by it, and the sound in the telephone T' is weak in consequence. If the current passes in opposite directions through the two wires of the helix (or returns on itself as in a resistance-coil), the self-induction is eliminated, and the current, having only to overcome the resistance of the circuit, is stronger than before, and the sound in the telephone T' is considerably louder in consequence.

If the self-induction has been eliminated and the sound is already loud, no further increase in the loudness is observed when the key is depressed and the double helix is short-circuited. If the self-induction has not been eliminated, and the sound is weak, it becomes loud when the key is depressed and the double helix is short-circuited, and it requires 3000 ohms to be introduced at R in order that the loudness may be the same whether the current passes through the resistance-coils and key or through the double helix. With a larger pair of coils substituted for the flat coils C and C', it requires 5000 ohms to be introduced at R in order to produce a similar result. As the resistance of the double helix is only 28 ohms, these results show, on the one hand, the deleterious effects which are produced by the self-induction of even a small coil, and, on the other, the importance of eliminating induction in conducting-circuits.

In the following experiments speech was transmitted by Bell's telephone, and two observers were employed, one at either end of the line.

The coils, keys, &c. were placed at one end of the line, and were under the control of one observer, whose chief duty was to read a paragraph of a newspaper in a monotone the loudness of which was kept as nearly as possible constant, so that the inflections of the voice might not be mistaken by the observer at the other end of the line for an increase or diminution in the loudness of the tone resulting from the manipulation of the apparatus while the reading was progressing.

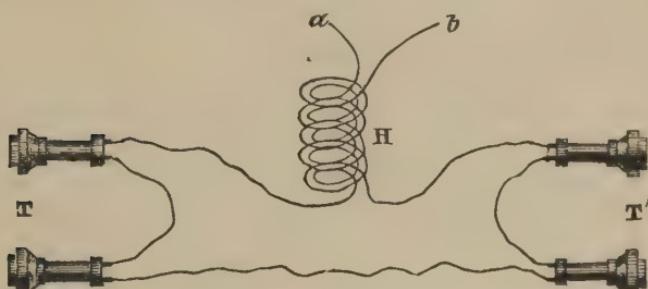
When a single circuit was employed which included one wire of the double helix, the loudness of the sound increased when the other wire of the helix was joined up as a separate

circuit—a result similar to that obtained (as already mentioned) by joining up the tertiary circuit fig. 1.

When two separate circuits were employed, each of which included one of the wires of the double helix, the helix acted as a "relay," and messages were transferred or translated from one circuit to the other with perfect facility from either end of the line, and conversation was carried on with the same distinctness as when a single circuit only was employed.

A single circuit was arranged as shown in fig. 3.

Fig. 3.



T and T' are the telephones, H is the double helix. The helix was joined up as shown in the figure, one end of each of its wires, *a* and *b*, being left unconnected and insulated. Thus arranged, there was a break in the continuity of the circuit, but nevertheless speech was transmitted with perfect distinctness, and conversation carried on with the same facility as in the previous experiments, the helix acting not as a conductor, but as a condenser, its two wires replacing the two sets of plates ; and it made no difference which of the ends of the wires of the helix were connected to the line-wires, or whether the currents entered the wires of the helix in the same or in opposite directions.

The helix in the last case having been replaced by a condenser, the other arrangements remaining unaltered, speech was again transmitted with as much facility and clearness as if the circuit had been complete—the capacity of the condenser, which was one microfarad, being amply sufficient to allow conversation to be carried on.



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# PROCEEDINGS

AT THE

## MEETINGS OF THE PHYSICAL SOCIETY

OF LONDON.

SESSION 1878-79.

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February 2nd, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following were elected Members of the Society:—

M. T. CORMACK, M.A.; C. J. FAULKNER, M.A.; C. W. JONES, F.R.A.S.;  
C. LEUDES DORF, M.A.; C. E. WALDUCK.

Prof. S. P. THOMPSON exhibited an experiment illustrating Am-  
père's law of parallel voltaic currents.

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February 16th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society:—

G. HERBERT WEST, M.A.

The following papers were read:—

“On Grove's Gas-Battery.” H. F. MORLEY, B.A.

“On the Harmonograph.” S. C. TISLEY.

“On a modified form of Lippmann's Capillary Electrometer, and  
its employment for the detection of the Currents in Bell's Tele-  
phone.” F. PAGE, B.Sc.

Exhibition of a Lantern-Galvanometer. Prof. S. P. THOMPSON.

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March 2nd, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following were elected Members of the Society :—

J. PARKE KIRKMAN; Dr. W. J. RUSSELL, F.R.S.

The following papers were read :—

“On the Coloured Figures caused by the Vibrations of Thin Films.” SEDLEY TAYLOR, M.A.

“On Mr. Edison’s Phonograph.” W. A. PRECE.

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March 16th, 1878.

*Special General Meeting.*

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The President of the Physical Society of Paris was elected an *ex officio* Member of the Society.

*Ordinary Meeting.*

The following were elected Members of the Society :—

J. S. BERGHEIM, C.E.; W. M. HICKS, M.A.; Dr. J. HOPKINSON, C.E.;  
Miss EDITH PRANCE; T. WILLS.

The following papers were read :—

“On the Transmission of Vocal and other Sounds through Metallic Wires.” W. J. MILLAR.

“On Thermoelectric Currents in Strained Wires.” G. W. von TUNZELMANN.

“On the Composition of Rectangular Vibrations.” Prof. W. G. ADAMS, F.R.S.

“On the Passage through Colloids of the Products of Electrolysis.” F. GUTHRIE, F.R.S.

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March 30th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following were elected Members of the Society :—

SHELFORD BIDWELL, M.A., LL.B.; WILLIAM GRANT; EDMUND GURNEY; JAMES HESLTINE SMITH.

The following papers were read :—

“On Byrne’s Pneumatic Battery.” W. H. PREECE.

“On an Arrangement for obtaining Uniform Rotation.” LORD RAYLEIGH, F.R.S.

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April 13th, 1878.

Prof. R. B. CLIFTON, F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society :—

Rev. T. NEVILLE HUTCHINSON, M.A.; Dr. B. W. RICHARDSON, F.R.S.;  
WILLIAM CAMPBELL; R. W. F. HARRISON.

The following papers were read :—

“On the Transmission of Vocal Sounds through Metallic Wires.”  
MESSRS. NIXON and HEAVISIDE.

“On the Photographs of the Less-refrangible end of the Spectrum obtained by means of Diffraction-gratings.” CAPT. ABNEY, C.E., F.R.S.

“On the Influence of Heat on the Transpiration of Gases.” Prof. FRANK GUTHRIE.

Exhibition of Models of Crystals. Mr. BAUERMANN.

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May 11th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

PHILIP MAGNUS, B.A., B.Sc.

The following papers were read :—

“On Recent Advances in the Chemistry of the Sun.” J. NORMAN LOCKYER, F.R.S.

“On the effect of Stress on the Magnetization of Iron, Nickel, and Cobalt.” Sir WILLIAM THOMSON, F.R.S.

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May 25th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following were elected Members of the Society :—

WILLIAM ROBERT PHELIPS; GEORGE MALTHUS WHIPPLE, B.Sc., F.R.A.S.; THOMAS McENIRY; W. KIESER.

The following papers were read :—

“On Brass Wind Instruments as Resonators.” J. N. BLAIKLEY.

“On the effect of Torsion on the Electrical Conductivity of Brass.” Sir WILLIAM THOMSON, F.R.S.

Exhibition of Photograph of Solar Spectrum taken by means of a Diffraction-grating. Dr. RUTHERFORD.

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June 8th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

RICHARD H. SOLLY, F.G.S.

The following papers were read :—

“On the Microphone.” Prof. HUGHES.

“On the Reflection of Light from the surface of Potassium Permanganate.” Sir JOHN CONROY, Bart., M.A.

“Electrical Properties of Bees’-wax and Lead-Chloride.” Prof. W. E. AYRTON.

Exhibition of an inexpensive form of Optical Bench. Prof. S. P. THOMPSON.

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June 22nd, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

F. W. GRIERSON.

The following papers were read :—

“On a new Polariscopic.” The PRESIDENT.

“On Starch and Unannealed Glass under the Polariscopic.”  
WALTER BAILY, M.A.

“On the Flow of Water from Orifices at different Temperatures.”  
Prof. W. C. UNWIN.

“On Complementary Colours.” Dr. GORHAM.

“On Magnetic Figures illustrating Electrodynamic Relations.”  
Prof. S. P. THOMPSON.

“On the Coordination of Space.” C. H. HINTON.

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November 9th, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

SIR FREDERICK ELLIOT.

The following papers were read :—

“On the Interference of Diffused Rays of Light by Thick Plates.”

The PRESIDENT.

“On Mr. Edison’s Tasimeter and Carbon Telephone.” Prof. W. F. BARRETT.

Exhibition of some Electric Lamps without Clockwork. WILLIAM LADD.

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November 23rd, 1878.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

The Rev. P. R. SLEEMAN, F.R.A.S.

The following papers were read :—

“On the Music of Colour and Visible Motion.” Profs. AYRTON and PERRY.

“On the Adjustment of a Collimator for Rays of different Re-frangibilities.” Dr. A. SCHUSTER.

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December 14th, 1878.

Prof. W. G. ADAMS, F.R.S., President, and afterwards Prof.

G. C. FOSTER, F.R.S., Vice-President, in the Chair.

The following were elected Members of the Society :—

WILLIAM GLEED, B.A.; JAMES GORDON McGREGOR, M.A., D.Sc.

The following papers were read :—

“On a Condenser of Variable Capacity.” C. V. BOYS.

“On a Differential Water-vapour Thermometer.” Dr. O. J. LODGE.

“On the Surface-tension of Liquid Sulphurous Anhydride.” J. W. CLARK.

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January 25th, 1879.

Prof. G. C. FOSTER, Vice-President, in the Chair.

The following were elected Members of the Society :—

ALEXANDER MACDONELL, B.A.; E. RAY LANKESTER, F.R.S.

The following papers were read :—

“On a Constant Bichromate-of-Potash Battery.” D. ERCK.

“On the Vibration of Metallic Rods.” F. GUTHRIE.

Exhibition of Commutators and Resistance-boxes by W. KIESER.

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*Annual General Meeting.*

February 8th, 1879.

Prof. W. G. ADAMS, F.R.S., President, in the Chair.

The following Report of the Council was read by the President :—

The position and prospects of the Society continue to give the Council unmixed satisfaction, and its usefulness is steadily increasing.

The number of Members has risen from 232 at the date of the last Annual Meeting to 270 at the present time, and of the 38 new Members 16 have compounded. The value and interest of the papers, which have been more numerous than in any previous year, have been well sustained.

The Council regret that the Society has lost by death a Member, Capt. R. G. Scott.

Captain R. G. Scott, R.E., son of the Rev. Dr. Scott, of the Methodist College, Belfast, was educated principally in Ireland. He obtained his Commission in the Royal Engineers on the 25th of January, 1862. During service in the Mauritius he suffered severely from fever, one attack nearly proving fatal. He returned to England with a constitution seriously impaired; but this, however, did not prevent his studying Electricity with great ardour. His capacity for work and talent for organization enabled him to render important public service in connexion with experiments at Portsmouth on the use of large charges of gun-cotton in submarine mines; and his zeal and ability being recognized by his official superiors, he was appointed an Assistant Instructor in Telegraphy at the School

of Military Engineering at Chatham, where his skill in Mathematics in its applications to Electricity was of much value. He died, March 16th, 1878, at the age of 35, too young to have made his name widely known ; but his geniality, wit, and musical talent will be long remembered in his own circle of friends.

In accordance with the intimation contained in last year's Report, an opportunity was afforded to each of the Members of expressing an opinion as to the desirability of changing the time of meeting. Replies were received to the circular issued by the Council from 186 out of the 232 Members ; and although the change was strongly urged by some, the Council did not consider that sufficient support was given to the proposal to justify them in altering the present arrangement.

The Library continues to progress satisfactorily. The following periodical works are regularly received, and are available for the use of Members :—the 'Journal de Physique,' Wiedemann's 'Annalen,' and the 'Beiblätter.' It has also been decided to purchase a complete set of 'Carl's Repertorium,' which will form a valuable addition to our collection. During the past year several foreign and other publications have been received, and the thanks of the Society have been given to the respective Donors. Among these the following may be mentioned :—A volume of the 'Annuaire du Bureau des Longitudes,' presented by our distinguished Honorary Member M. J. Janssen, which contains a review, written by himself, "On recent progress in Solar Physics;" Bibliographie Analytique &c., J. Plateau; Saunier's Horology, E. Rigg; University of Melbourne, Calendar and Exam. papers; Journ. Soc. Telegraph Engineers; Meteorology of Bombay Presidency, from the India Office; Connecticut Academy Transactions; Fourier's Theory of Heat (Freeman), Pitt Press; numerous papers from the Royal Society of New South Wales.

The Council have availed themselves of the power conferred on them by the amended Bye-Laws to recommend, as an ex-officio Member of the Society, the President of the Physical Society of Paris, and they are gratified at being able to congratulate the Members on the connexion which has been thus established with this distinguished Foreign Body. The Members of the Society will be gratified to hear of the satisfaction with which the announcement was received by the Members of the Physical Society of Paris. The President of the French Physical Society writes :—"Cette nouvelle a été accueillie avec la plus vive satisfaction, et l'assemblée a immédiatement voté à l'unanimité que le President de la

Société de Physique de Londres serait inscrit à perpétuité parmi les Membres de la Société Française de Physique. Nous espérons que les liens qui vont unir les deux Sociétés se fortifieront de jour en jour, et nous sommes personnellement heureux d'être chargés par nos confrères de vous adresser à vous et aux Physiciens de Londres les premières paroles de bonne confraternité."

The Council feel that no observations are necessary from them as to the illustrious Physicists whose names are submitted to you to day for election as Honorary Members, as it will be evident that their union with the Society cannot fail to add to its dignity.

The Society's Reprint of Sir Charles Wheatstone's published scientific papers is nearly complete. All the papers of which the existence is known to the Editors are in type, and, with the exception of the last two sheets, have been corrected and returned for press. The collected papers will form a volume of about 370 pages, which the Council confidently hope to place in the hands of Members in a few weeks.

The question of reprinting important Physical papers, to which allusion was made in last year's Report, has not been lost sight of; but owing to the expenses incurred for registration and for the re-print of Sir C. Wheatstone's papers, it has been found necessary to defer active steps until the current year.

The Council again regret that so few of the Members communicate papers to the Society: during the past year, however, the proportion of authors to papers read has been greater than in the previous year, and in the future it may perhaps be found useful for the Society to indicate definite subjects for research. In this connexion the Council would point to the words of Dr. Spratt, who, writing soon after the foundation of the Royal Society, which in organization our own so much resembles, observes, "That though the Society is not yet four years' old, and has been of necessity hitherto chiefly taken up about preparatory affairs, yet even in this time . . . they have had successes in the trial of many remarkable things;" and he suggests "that by laying down on what course of discovery they intend to proceed, the gentlemen of the Society may be more solemnly engaged to prosecute the same, as they will not be able handsomely to draw back and to forsake such honourable intentions."

Our grateful thanks are due to the Lords of the Committee of Council on Education for their continued permission to hold our Meetings in the Science Schools, South Kensington.

At the time of our Annual Meeting last year we were only just beginning to recover from the excitement which was created by the invention of the Telephone, an instrument which, quite apart from the uses to which it may be applied, is of great interest to scientific men, and would have delighted Faraday, since it gives, by means of magneto-electricity, a very complete illustration of the laws of conservation, transformation, and dissipation of energy.

The year had scarcely begun when we were startled at the fertility of resource of a far-famed inventor, who sends to us a scroll on which the very tones of his voice are engraved, and which may yet be heard over and over again and handed down to future ages.

The invention of the Phonograph gave rise to investigations on the Analysis of Vowel-Sounds and Resonance-Cavities by Prof. Fleeming Jenkin and others, which bear out the conclusions drawn by Prof. Willis and by Wheatstone from their experiments, that each vowel-quality is given by a particular resonator, and that the pitch of maximum resonance of the resonator is an important element in determining the vowel character of the sounds produced. They also support the view of Prof. Donders, that there is a pitch of maximum resonance in human mouth-cavities for the vowel *ö*, but give no such characteristic tone for the vowel *ii*. And they confirm the statement of Helmholtz that vowel-sounds are made up of harmonic partial tones.

The subject of the quality of sounds and resonance has been illustrated before the Society by Mr. Blaikley, who gave us an interesting paper, "On Brass Wind Instruments as Resonators."

The discovery of the Telephone led people to think of ordinary mechanical methods of transmitting vibrations, which were investigated by Wheatstone forty or fifty years ago, and two interesting papers on the transmission of Vocal and other Sounds through Metallic Wires, by Mr. Millar and by Messrs. Nixon and Heaviside, have been read before the Society.

In the Telephone, the voice reproduced at the receiving end must, from the dissipation of energy, be fainter than the human voice, which is the motive power of the apparatus. In the Microphone of Prof. Hughes, and in the Carbon Telephone of Mr. Edison, a transmitter of pieces of carbon or other substances in contact is employed to modulate the intensity of a battery current; and the tread of a fly, or the scratching of a single hair, or even the diffusion of a gas through a porous substance, may give rise to vibrations which act as a battery key to regulate and modify the flow of the current, so as to

cause it to reproduce the same vibrations in the telephone plate, which is used as a receiving instrument.

In his Tasimeter, Mr. Edison has shown that the same combination of pieces of carbon may be employed to measure slight alterations of pressure, and so to measure slight changes of temperature by the expansion of a strip of ebonite or other substance, which presses on the carbon disks and alters the resistance of the electric circuit.

Prof. Hughes has shown that a Microphone may be used as a relay in an extended Telephone circuit, and also that messages may pass opposite ways through the Microphone without interfering with one another. It has also been shown that this instrument may be of service in surgical operations, and that it may possibly be of service in enabling the deaf to hear.

In connexion with this subject, as well as with the ordinary methods of transmitting sound-vibrations, I may quote the words of Hooke, who was Physical Demonstrator to the Royal Society rather more than 200 years ago.

Hooke, in the Preface to his 'Micrographia,' published in 1665, says:—"As glasses have highly improved our seeing, so, tis not improbable, but that there may be found mechanical inventions to improve our other senses of hearing, smelling, tasting, touching. Tis not impossible to hear a whisper a furlong's distance, it having been already done; and perhaps the nature of the thing would not make it more impossible though the furlong should be ten times multiply'd. And though some famous authors have affirmed it impossible to hear through the thinnest plate of Muscovy glass; yet I know a way by which tis easie enough to hear one speak through a wall a yard thick. It has not yet been thoroughly examined how far Otocousticons may be improved, nor what other wayes there may be of quickening our hearing, or conveying sound through other bodies then the air; for that that is not the only medium I can assure the reader that I have by the help of a distended wire propagated the sound to a very considerable distance in an instant, or with as seemingly quick a motion as that of light, at least incomparably swifter then that, which at the same time was propagated through the air: and this not only in a straight line, or direct, but in one bended in many angles."

These remarkable inventions, which one after another have created so much excitement, and which have even sent a thrill through the most learned of Societies, have been well illustrated at our Meetings.

At the same time the list of papers read before the Society shows that we have had important communications on all branches of Physics. In Electrical science we have had suggestive papers from Sir William Thomson on the relation between Stress and Magnetization, and again, on the relation between Stress and Electrical Conductivity; by Mr. Tunzelmann on Straining of Wires and Thermo-electric currents; and from Prof. Ayrton on Specific Inductive Capacity. Among our communications on the Interference and Polarization of Light, we have had a very carefully worked out paper by Mr. Walter Baily, "On Starch and Unannealed Glass under the Polariscopic." Bearing on that branch of science with which the name of M. Plateau is associated, in which we make some attempt to approach the workings of molecules, we have had a paper from Prof. Unwin, and a paper on the Surface-tension of Liquids from Mr. Clark; and we shall none of us be in danger of forgetting the beauty of the coloured figures caused by the vibrations of Mr. Sedley Taylor's soap-films.

There is also an appropriateness in connecting the name of M. Kirchhoff with our Society, for, as regards Spectrum Analysis, we have been highly favoured: we have had a paper by Mr. Lockyer, "On Recent Advances in the Chemistry of the Sun," and have seen a new and wide field of research opened out by Captain Abney's success in photographing the less-refrangible end of the spectrum. We have also had the honour of welcoming amongst us Mr. Rutherford from America, who exhibited to the Society the remarkable photograph of the solar spectrum which he has taken, and to whom we are indebted for the production of the most perfect diffraction-gratings which the world has ever seen.

We thus see, from a hasty glance at the papers which have come before us during the past year, that something has been gathered from each of the many branches into which Physics is divided.

There is still one subject, which is by no means new, but to which I should draw your attention in reviewing what has been done during the past year. Through the kindness of Dr. Siemens, Mr. Latimer Clark, Prof. Tyndall, and Mr. Spottiswoode, I am able to-day to show you the results of various applications of the electric current for the production of light. A communication on this subject will be made to the Society by Mr. Shoolbred after the conclusion of the business of the Annual General Meeting.

The Society then proceeded to the election of Council and Officers for the ensuing year, and the following gentlemen were declared duly elected :—

*President*.—Prof. W. G. ADAMS, M.A., F.R.S.

*Vice-President* (who has filled the Office of President).—Prof. G. C. FOSTER, F.R.S.

*Vice-Presidents*.—Prof. R. B. CLIFTON, M.A., F.R.S.; Lord RAYLEIGH, M.A., F.R.S.; W. SPOTTISWOODE, LL.D., Pres. R.S.; Sir WILLIAM THOMSON, LL.D., D.C.L., F.R.S.

*Secretaries*.—Prof. A. W. REINOLD, M.A.; W. CHANDLER ROBERTS, F.R.S.

*Treasurer*.—Dr. E. ATKINSON.

*Demonstrator*.—Prof. F. GUTHRIE, Ph.D., F.R.S.

*Other Members of Council*.—Capt. W. DE W. ABNEY, R.E., F.R.S.; WARREN DE LA RUE, D.C.L., F.R.S.; Major E. R. FESTING, R.E.; Prof. F. FULLER, M.A.; W. HUGGINS, D.C.L., F.R.S.; Prof. A. B. W. KENNEDY, C.E.; Prof. H. M'LEOD; The EARL OF ROSSE, D.C.L., F.R.S.; G. JOHNSTONE STONEY, M.A., F.R.S.; R. WORMELL, D.Sc.

After the names of the Officers and Council had been announced from the Chair, votes of thanks were proposed to the Lords of the Committee of Council on Education, to the President, to the Treasurer, Demonstrator, the Secretaries, and to the Auditors.

<i>Dr.</i>	<i>£ s. d.</i>	<i>Cr.</i>	<i>£ s. d.</i>
Balance in Bank December 31st .....	154 8 4		6 10 3
Advances-Fees .....	38 0 0	Purchase of £160 5 per cent. Midland Pre- ference Stock .....	198 18 3
scriptions for 1876 .....	5 0 0	Reports of Meetings .....	13 7 3
", 1877 .....	17 0 0	Messrs. Miller and Wiggins for expenses of Registration .....	70 16 9
", 1878 .....	120 0 0	Messrs. Taylor and Francis :— Printing Proceedings &c., part iv vol. ii .....	23 17 6
", 1879 .....	4 0 0	Postage and addressing .....	1 19 6
positions .....	160 0 0	Separate copies for Members .....	4 14 6
dividends on £400 4 per cent. Furness Dene- nre Stock, less Income Tax, 4s. 8d. ....	15 15 4	Miscellaneous Printing .....	21 18 6
debt on £300 5 per cent. Midland Pre- ference Stock, less Income Tax, 4s. 4d. ....	14 15 8	Commission on sale of Everett's C.G.S. ....	1 2 4
of Everett's C.G.S. ....	11 2 4	Reprint of Sir C. Wheatstone's papers ...	110 16 0
scription paid to Taylor and Francis .....	1 1 0	Mr. Richardson, of Greenwich :— Miscellaneous Printing .....	1 11 6
		Mr. Webb : Printing .....	0 19 6
		Messrs. Smith and Son : Advertising .....	3 19 6
		Mr. Clarke : Engraving .....	3 2 3
		Periodicals .....	5 8 0
		Stationery .....	1 17 10
		Petty Cash :— Mr. Roberts .....	16 6
		Mr. Reinold .....	1 15 10
		Dr. Atkinson .....	2 13 6
		Chapman : Attendance at Meetings .....	5 5 10
		Cash in Bank .....	4 12 9
		Balance due by Treasurer .....	55 9 6
			4 15 2
			<b>£541 2 8</b>

We have examined the above Account, which we find correct, and that there is a Balance due by the Treasurer of Four Pounds, Fifteen Shillings, and Two Pence.

London, February 7th. 1879

B. WOODD SMITH, } *Auditors.*  
ROBT. J. LECKY }

## PROPERTY ACCOUNT. PHYSICAL SOCIETY.

ASSETS.	£ s. d.	LIABILITIES.	£ s. d.
Subscriptions due .....	40 0 0	Wheatstone's Reprint .....	90 0 0
£400 4 per cent. Debenture Stock Furness Railway at 103 .....	412 0 0	Subscriptions in advance .....	4 0 0
£460 5 per cent. Preference Stock Midland Railway at 123 .....	535 0 0	Due for Everett's C.G.S.....	15 0 0
Due by Treasurer .....	4 15 2	Balance .....	968 4 8
Balance in Bank .....	55 9 6		
			£1077 4 8
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We have examined the above Account, which we find correct, and that the Assets of the Society exceed the Liabilities by Nine Hundred and Sixty-eight Pounds, Four Shillings, and Eight Pence. We have also examined the Securities at the Bankers.

London, February 7th, 1879.

B. WOODD SMITH, } *Auditors.*  
ROBT. J. LECKY. }

PROCEEDINGS  
AT THE  
MEETINGS OF THE PHYSICAL SOCIETY  
OF LONDON.

SESSION 1879-80.

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February 8th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society:—

W. N. SHAW, M.A.; G. B. FINCH.

The following papers were read:—

“On the Variation with Temperature of the Thermal Conductivity of a bar heated at one end.” By O. J. LODGE, D.Sc.

“On Electric Lighting, Dynamo-Electric Machines, and Electric Lamps.” By J. N. SHOOLBRED, C.E.

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February 22nd, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society:—

Prof. J. C. ADAMS, M.A., D.C.L., F.R.S.; Prof. G. D. LIVEING, M.A.;  
F. W. PETERSON; Rev. COUTTS TROTTER, M.A.

The following papers were read:—

“On an Electric Current Regulator.” By Dr. C. W. SIEMENS, F.R.S.

“On Spectra of Lightning.” By Dr. A. SCHUSTER.

"Some remarks on Dr. Lodge's paper 'On the Variation with Temperature of the Thermal Conductivity of a Bar.'" By Prof. W. E. AYRTON.

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March 8th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society :—

Dr. T. ARCHER HIRST, F.R.S.; F. JACOB.

The following papers were read :—

"On a New Theory of Terrestrial Magnetism." By Profs. W. E. AYRTON and J. PERRY.

"On an Anomalous Experiment with the Quadrant Electrometer." By Dr. J. HOPKINSON, F.R.S.

"On the Maintenance of Constant Temperatures and Pressures." By F. D. BROWN.

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March 22nd, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair

The following was elected a Member of the Society :—

Lieut. HASTINGS R. LEES; R.N.

The following papers were read :—

"On the Photographic Method of Registering Absorption-Spectra." By Capt. ABNEY, F.R.S.

"On the Fracture of Colloids." By Dr. F. GUTHRIE, F.R.S.

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April 26th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following papers were read :—

"On some Phenomena connected with Magneto-electric Induction." By Dr. F. GUTHRIE, F.R.S., and C. V. BOYS.

The following Notes from the Physical Laboratory of University College, Bristol. By Prof. S. P. THOMPSON :—

1. On the Source of Sound in the Bell Telephone.
2. On a new variety of Magnetic Figures.

3. On Magnetic Figures for demonstration.
  4. On the Magnetic behaviour of fixed Iron filings.
  5. Magnetic Figures of Three Dimensions.
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May 10th, 1879.

**Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.**

The following was elected a Member of the Society :—

**JOHN CASTELL EVANS.**

The following papers were read :—

“On an Inquiry into the suppression of the Induction-disturbance of the Telephone.” By Prof. W. F. BARRETT.

An Account and Exhibition of Gower’s Loud-speaking Telephone. By Mr. WOLLASTON.

“On the Divisibility of the Electric Light.” By W. J. WILSON.

“On a new form of Incandescent Electric Lamp for Surgical Purposes.” By W. H. COFFIN.

May 24th, 1879.

**Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.**

The following were elected Members of the Society :—

**WALTER EMMOTT ; SEDLEY TAYLOR, M.A.**

The following papers were read :—

“On a New Harmonograph.” By W. J. WILSON.

“On a New Induction-Balance.” By Prof. D. E. HUGHES.

“On the Examination of certain Alloys by the Aid of the Induction-Balance.” By W. C. ROBERTS, F.R.S.

“On a New Pump without Valves.” By Dr. ERCK.

June 14th, 1879.

**Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.**

The following were elected Members of the Society :—

**DONALD M’ALISTER, M.A. ; ST. GEORGE LANE FOX.**

The following papers were read :—

“On the Suppression of the Induction-disturbance in a Telephone Circuit.” By Prof. H. M’LEOD.

"On a New Reversing Key for Electrometer Work." By Dr. O. J. LODGE.

"On the Sensitiveness of Electrical Discharges in Vacuo." By W. SPOTTISWOODE, F.R.S., and J. F. MOULTON, M.A.

Dr. HENRY DRAPER gave an account of his observations on the bright lines of oxygen in the Solar Spectrum.

Specimens of Chromo-photographs by Dr. J. ALBERT of Munich were exhibited.

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June 21st, 1879.

Extra Meeting, held at the Royal Indian Engineering College,  
Cooper's Hill.

LORD ROSSE, F.R.S., in the Chair.

The following papers were read :—

"Experiments on the Friction of Water." By Prof. W. C. UNWIN.

"On a Method of determining the Vibration-number of Tuning-Forks." By Lieut. G. S. CLARKE, R.E.

"On an Electrical Clock." By Prof. M'LEOD.

"On the Surface-tension of Liquids at Temperatures near their Critical Points." By J. W. CLARK.

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June 28th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society :—

J. J. EASTICK ; J. FLETCHER MOULTON, M.A.

The following papers were read :—

"On a new Measuring-Polariscope." By Prof. W. G. ADAMS, M.A., F.R.S.

"On the Distribution of Heat in the Solar and other Spectra." By Sir JOHN CONROY, Bart., M.A.

"On the Conjugate Positions of two Circular Coils." By W. GRANT.

"On the Spirality of the Energy of a Magnet." By Dr. R. C. SHETTLE.

"Remarks on Profs. Ayrton and Perry's Theory of Terrestrial Magnetism." By Prof. ROWLAND, of Baltimore.

"On a modification of Arago's experiment." By WALTER BAILY, M.A.

"On a form of Galvanometer for showing the internal resistance of a battery." By CONRAD COOKE.

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November 8th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following papers were read:—

"On the Analogy between the Heat-conductivity and the Induction-Balance-effect of Tin-copper Alloys." By W. CHANDLER ROBERTS, F.R.S.

"On the Electrical Conductivity of the Alloys examined by Mr. Roberts." By Dr. O. J. LODGE.

"On a Standard Galvanic Cell." By Capt. ARMSTRONG, R.E.

"On the Incandescence of Electrodes, an effect observed by Prof. Pirani, of Melbourne." By Prof. F. GUTHRIE, F.R.S.

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November 22nd, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society:—

Prof. CALCOTT REILLY, M. Inst. C.E.;

Prof. A. H. HEATH, Assoc. Inst. C.E.

The following papers were read:—

"On a Retention-image Photometer." By Prof. F. GUTHRIE, F.R.S.

"On a Suggestion as to the Molecular constitution of Chlorine furnished by the Dynamical theory of Gases." By Prof. A. W. RÜCKER.

"On the effect of Temperature on certain forms of Induction-coils, with especial reference to the physiological effects in the human body." By Dr. R. C. SHETTLE.

Crossley's Telephone Transmitter was exhibited by Mr. WALTER EMMOTT.

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December 13th, 1879.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following were elected Members of the Society :—

HENRY RICHMOND DROOP, M.A.; RICHARD TETLEY GLAZEBROOK, M.A.; E. PATERSON; JOHN HENRY POYNTING, M.A.; Prof. H. A. ROWLAND; E. B. SARGENT, B.A.; R. C. SHETTLE, M.D.; JOHN GRAY, B.Sc.

The following papers were read :—

“On a new Wheatstone’s Balance for comparing Standard Coils.”  
By Dr. J. A. FLEMING.

“On a Dispersion-Photometer.” By Profs. AYRTON and PERRY.

“On the value of ‘g’ in Japan.”

A new form of Spherometer, designed by Mr. WALTER GOOLDEN and constructed by A. HILGER, was exhibited and described.

January 24th, 1880.

Prof. W. G. ADAMS, M.A., F.R.S., President, in the Chair.

The following was elected a Member of the Society :—

W. E. VINSON.

The following papers were read :—

“On Induction in Telephonic Circuits.” By W. GRANT.

“On Intermittent Currents, and the theory of the Induction-Balance.” By Dr. O. J. LODGE.

“On a Liquid Voltaic Arc.” By C. V. BOYS.

A Talking-machine was exhibited and described by its constructor, Mr. F. FABER.

*Annual General Meeting.*

February 14th, 1880.

Prof. ADAMS, M.A., F.R.S., President, in the Chair.

The following Report of the Council was then read by the President :—

Those who have interested themselves in the welfare of our

Society cannot fail to have been gratified by the progress that has been made during the past Session. The papers submitted to the Society, which are more numerous than in any previous session, have for the most part been prepared by the respective authors for publication. This fact has given the Council much satisfaction, as it has enabled the Publication Committee to issue the 'Proceedings' with greater promptitude than heretofore. While the Council hopes that Members will, as far as possible, provide written papers and abstracts, it is anxious to encourage the exhibition of the simplest new experiment at the Meetings, or the informal communication of any results of a novel and interesting character.

Last year *i.e.* from February 1878 to February 1879, fifteen papers were printed in our Proceedings. This year there were fourteen papers already published in October last, and during the past week another number of the Proceedings has been published containing ten papers, making twenty-four papers during the year, and including papers which have been read up to our last Meeting.

The Society is to be congratulated on having two energetic and efficient Secretaries, who have during the past year brought the publication so closely up to date that the number of Proceedings containing a valuable paper read at our last Meeting on January 24 is already in the hands of Members before the present Meeting of the Society.

The Society is also to be congratulated on the increase in the number of papers considered worthy of publication.

A study of our Proceedings will show that in these days of hasty printing they do not encumber, and thereby obstruct, the progress of Science, but that they form a valuable contribution to the literature of Physics.

On the day of our last Annual Meeting Mr. Shoolbred gave an account of the more recent development of electric lighting, illustrated by diagrams of the various systems in use; and at the next Meeting Dr. Siemens described his new electric current regulator, based on the heating of a wire by the passage of an electric current through it. This apparatus he devised to regulate the flow of a current so as to maintain it uniform, however the resistance of the circuit or the electromotive force may vary. Early in March Capt. Abney read an important paper on obtaining photographic records of absorption-spectra; and Prof. Guthrie gave the first results of an elaborate investigation into the fracture of colloids. In April, in conjunction with Mr. C. V. Boys, he described some ex-

periments on the subject of Arago's rotation, in the course of which they observed that circular cuts in the disk are more important than radial cuts; and by extending their research to liquids they have arrived at an interesting method of determining the conductivities of liquids, in which the errors due to polarization are eliminated.

At our Meeting in May, Prof. Hughes exhibited his induction-balance and sonometer, which promise to play so important a part in physical research; and none can fail to recognize the care, skill, and untiring patience that must have been devoted to experiments that have resulted in these remarkable instruments. The beautiful research on the stratified discharge in vacuum tubes, by Messrs. Spottiswoode and Moulton, was illustrated before the Society by the latter physicist; and on the same day we were favoured by a communication from Dr. H. Draper on the presence of oxygen in the sun.

A very interesting extra Meeting of the Society was held on the 21st of June at the Royal Engineering College, Cooper's Hill, by the kindness of Col. Chesney, when papers were read by Profs. Unwin and McLeod, Lieut. Clarke, and Mr. J. W. Clark, all members of the College staff.

A new theory of the earth's magnetism, put forward by Messrs. Ayrton and Perry in the earlier part of the session, was based on the results of experiments made by Prof. Rowland, of Baltimore; and we were fortunate, at our concluding meeting of last Session, in having Prof. Rowland himself with us, who gave an account of his experiments on which the theory was based, and his views as to how far it is tenable.

An interesting investigation in the dynamical theory of gases has afforded Prof. Rücker a suggestion as to the constitution of chlorine, and the sonometer and induction-balance have laid open a rich field of physico-mathematical research, which has been taken advantage of by Mr. Poynting, who studied the graduation of the former instrument, and by Dr. Lodge as regards the induction-balance and the general theory of intermittent currents. Mr. Roberts has shown experimentally that in the case of the copper-tin alloys the curve of the conductivity for heat corresponds closely with that representing the induction-balance effect, at the same time pointing to the incomplete character of Matthiessen's curve of electric conductivity. A paper on an allied subject, the induction in telephonic circuits, was read by Mr. Grant.

Prof. Pirani, of Melbourne, drew the attention of Dr. Guthrie to

a remarkable effect that is produced when the terminals of a powerful battery are immersed in succession in various liquids, and Prof. Guthrie exhibited a number of experiments illustrative of the subject before the Society.

Several new instruments of research have been brought before us during the past year ; among them may be mentioned Prof. Guthrie's image-retention photometer, a measuring polariscope by the President, and a valuable modification of the Wheatstone Bridge, devised by Dr. A. J. Fleming.

The Conversazione given by the President and Council on the 7th inst. was in every way successful. About 600 members and their friends were present. The Council looks forward to repeating such meeting from time to time.

The Library Committee reports that the Library consists now of 236 separate volumes and about 150 pamphlets.

Last summer an invitation was issued to Members to aid in the formation of the Library by contributing copies of their own researches and other works. In response to this, many valuable contributions have been received. Amongst these may be mentioned works by Descartes, Helmholtz, Tyndall, and Thomson, presented by J. Sterling ; a very large collection of books and pamphlets on subjects relating to electricity, and having an especial historical interest, presented by Latimer Clark ; Plateau's 'Statique Expérimentale et Théorique des Liquides,' presented by the author ; the 'Observatory,' nos. 1-27, presented by W. H. M. Christie ; about twenty volumes on miscellaneous scientific subjects, presented by J. B. Huntington ; Janssen's 'Mélanges Scientifiques,' comprising nearly a complete set of his works, by the author. The following gentlemen have been also good enough to make very acceptable contributions :—W. Besant, M.A. (Whewell's 'History of the Inductive Sciences,' 3 vols.) ; Prof. B. Stewart (Treatise on Heat) ; Dr. W. M. Watts (Watts's 'Index of Spectra') ; Rev. J. Perry ('Meteorological Observations, Stonyhurst') ; R. H. M. Bosanquet, M.A. (Treatise on Temperament) ; Dr. W. Spottiswoode (Polarization of Light) ; F. D. Brown (Arnott's 'Natural Philosophy,' 2 vols.) ; E. Rigg, M.A. (Saunier's 'Treatise on Modern Horology').

The Council again propose to add two names, those of Clausius and Fizeau, to our list of illustrious Honorary Members, of whom it must be remembered that, in accordance with our Bye-laws, after this Meeting, only four will remain to be selected.

The claims of the distinguished men whose names are placed

before you for election as Honorary Members are so well known that it is scarcely necessary that special attention should be drawn to them.

M. HIPPOLYTE LOUIS FIZEAU is known for his investigations, some forty years ago in connexion with M. Foucault, on the use of bromine in the preparation of Daguerreotype plates, and on the action of the red rays on sensitive substances, also for his researches on the Electric Arc, as well as on the Interference and Polarization of Light, and the Interference and the Wave lengths of Heat radiation. But M. Fizeau is more widely known as having been the first to determine (more than thirty years ago) the velocity of light by actual experiment on the earth's surface, by sending a beam of light to a mirror, 8633 metres off, and measuring, by means of revolving wheels, the time it takes to go and return to the station of the observer. Soon after M. Fizeau carried out the experiment which had been suggested by Arago years before, founded on Wheatstone's method of the revolving mirror, and presented his results to the Academy in June 1850. He had previously presented a note on his method on May 6 of the same year, the day on which M. Foucault presented his complete memoir on the subject to the Academy.

M. RUDOLPH JULIUS EMMANUEL CLAUSIUS is well known for his investigations on the Mechanical Theory of Heat, and his work on the Kinetic Theory of Gases will now become more widely known to English readers through the translation which has lately been issued, with the sanction of Professor Clausius himself. It will perhaps be not too much to say that there is no one to whom we are more indebted for the creating anew and the complete development of this special branch of Science.

Our grateful thanks are, as heretofore, due to the Lords of the Committee of Council on Education for permission to hold our meetings in the Science Schools, and to Dr. Guthrie, who has continued to act as Demonstrator.

If we attempt to compare the progress made in Physics with the progress made in other branches of science, we shall find that not only will Physics stand well to the front, but that other Sciences are getting more and more interwoven with Physics, and are advancing, chiefly by means of the investigations and discoveries which Physics brings to their aid, and by reason of the mutual dependence of the various physical forces on one another.

The increasing demand for our 'Proceedings' by other scientific bodies would alone afford abundant proof of the appreciation in which the Society's work is held, even if the evidence afforded by

its continued growth were wanting. The number of Members has risen from 266, at the date of our last Annual Meeting, to 298 at the present time. 17 Members have compounded during the year.

The Society has to lament the loss of three of its Members.

Mr. RICHARD SECKER BROUGH, an original Member of our Society, was the youngest son of Thompson Brough, Esq., M.D. He was born at Killegan, in the county of Wicklow, on the 17th of October, 1846, and received his early education at a private school in Jersey, and later at the Victoria College. At Avranches he subsequently studied the Italian and German languages and Physical Science, and showed great interest in Mathematics.

It was about this time that Sir Stafford Northcote introduced the present system of examination for the Indian Telegraph Service. Mr. Brough was nominated for that service, and, after another year's study at Southampton and University College, London, he was appointed, by the Secretary of State for India, a fourth-grade Assistant Superintendent in 1869. His ability was so marked that he was appointed Assistant Superintendent of Stores in 1870. Shortly afterwards he was transferred to Madras to take charge of that important Telegraph Station. In March 1871 he was recalled to be appointed an Assistant to the Superintendent Electrician, which important position he held up to the time of his death. In the Electrician's office, where physical experiments of varied nature are daily executed, he had all the opportunity to develop his special talents, which he did with marked success. During Mr. Schwendler's absence from India, he was invariably deputed by the Director General to officiate for that officer, on account of the very great ability which he had shown in all the technical branches connected with telegraph administration. His latest practical work, in connexion with the Indian Telegraph, was undertaken with the special purpose of testing and repairing the faulty Paumben cables in connexion with the Ceylon cable.

Mr. Brough was the author of numerous papers on electrical subjects, which were published in the 'Proceedings of the Asiatic Society of Bengal.'

He was one of the most active members of the Asiatic Society, and since 1871 has been a member of the Physical Science Committee of that Society. He was elected an associate member of the Institution of Civil Engineers. He was also a member of the Society of Telegraph Engineers in England.

His kind and generous disposition was especially shown towards those who had the fortune to serve under him.

Mr. LE NEVE FOSTER was perhaps the best known of those Members whom the Society has lost by death during the past year.

Mr. Foster, who died in February last, had been Secretary of the Society of Arts since 1853. He was born in 1809, and was the son of Mr. Peter Le Neve Foster, of Lenwade, Norfolk. He was educated under Valpy at Norwich, and from thence went up to Trinity Hall, Cambridge, where he was thirty-eighth Wrangler in the Mathematical Tripos of 1830, and was afterwards elected Fellow of his College. Called to the bar at the Middle Temple in 1836, he practised as a conveyancer until he became Secretary to the Society of Arts. He was intimately associated with all the earlier International Exhibitions, from 1851 downwards. Taking a general interest in many branches of Science, the subject of Photography was the one to which he principally devoted himself. He was one of the first to practice the art as a scientific amateur, and wrote a good deal on it, principally in the 'British Journal of Photography.' He was one of the founders of the Photographic Society, and served for many years on its Council. For twelve years he acted as Secretary of the Mechanical Section of the British Association, the last time being at the Meeting at Brighton in 1872. Mr. Foster's long connexion with the Society of Arts made his a well-known figure in all scientific circles; and it may certainly be said that wherever he was known he was greatly liked. He was not an original Member of the Society, but joined it in 1877, soon after its formation.

The next on our obituary list is one who was cut off before he had time to confirm the reputation which certainly would have been his in a very few years.

Mr. THOMAS WILLS was one of the most promising of our younger generation of chemists. He had not long been a Member of our Society, for it was only in March 1878 that he joined it. Most of his work lay in matters outside our range; though his recent work, in connexion with gas-lighting and of the products of combustion in the electric arc, was associated not less with physics than with chemistry.

Mr. Wills was born in 1850, and was educated at University College School and at King's College. In 1868 he became Assistant to Dr. Odling at Bartholomew's Hospital; and when Dr. Odling

became Fullerian Professor at the Royal Institution, Wills accompanied him as Assistant. In 1873 he resigned his post to become Demonstrator in Chemistry at the Royal Naval College, Greenwich, and in the year following he became Secretary to the Chemical Section of the Society of Arts, on its foundation. He was Secretary for one year to the Chemical Section of the British Association, and was a Member of the Association Committee for ascertaining the best methods of utilizing the illuminating power of coal gas. He read many papers before the Chemical Society, the British Association, and the Society of Arts, and other Societies. For one of his papers he received a Society of Arts Medal, as he did also for a series of Lectures on Explosions in Coal-mines, given in 1878 before that Society.

Though Prof. CLERK MAXWELL was not a Member of the Society, the Council cannot refrain from recording their share in the profound regret that has been so widely expressed for his untimely death; for, in the graceful words of the President of the Royal Society, "in Maxwell the full maturity of a mind which had suffered no check or shadow of abatement, was devoted to the foundation of a more thorough knowledge of molecular physics and electrical laws than had hitherto been attained."

The publications other than the 'Proceedings,' which are intended to form an important feature of our work, still actively engage the attention of the Council. The first work published by the Society, 'The Centimetre-gramme-second System of Units,' by Prof. Everett, was found to be so useful that the entire edition was rapidly distributed; and, as a second edition was called for, the Council willingly acceded to the request of Prof. Everett, that his work, supplemented by a collection of physical data, should form one of the well-known series of mathematical treatises published by Messrs. Macmillan. A Dutch translation of the first edition appeared in 1877.

By the issue of the collected works of the late Sir Charles Wheatstone an important addition has been made to scientific literature, and the Members cannot fail to share in the appreciation with which it has been so generally received.

The Reprint Committee has decided to undertake the translation of the more important of Volta's papers on Electricity. They are supported in this decision by the opinions of Sir William

Thomson and Professor Clifton, who have given valuable advice as to the selection of papers for translation. Arrangements have been made for the translation of some of these papers under the supervision of the Committee, and the work will be taken in hand at once.

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The Treasurer presented an audited Balance-sheet, and the Society then proceeded to the election of the Council and Officers for the ensuing year, and of Honorary Members. Mr. BIDWELL and Mr. GRANT were appointed Scrutators. The following were declared duly elected:—

*President*.—Sir Wm. THOMSON, LL.D., D.C.L., F.R.S.

*Vice-President* (who has filled the Office of President).—Prof. W.G. ADAMS, M.A., F.R.S.

*Vice-Presidents*.—Prof. R. B. CLIFTON, M.A., F.R.S.; Lord RAYLEIGH, M.A., F.R.S.; W. SPOTTISWOODE, LL.D., Pres.R.S.; W. W. HUGGINS, D.C.L., F.R.S.

*Secretaries*.—Prof. A. W. REINOLD, M.A.; W. CHANDLER ROBERTS, F.R.S.

*Treasurer*.—Dr. E. ATKINSON.

*Demonstrator*.—Prof. F. GUTHRIE, Ph.D., F.R.S.

*Other Members of Council*.—Capt. W. De W. ABNEY, R.E., F.R.S.; WALTER BAILY, M.A.; J. H. COTTERILL, M.A., F.R.S.; WARREN DE LA RUE, D.C.L., F.R.S.; Major E. R. FESTING, R.E.; Prof. G. C. FOSTER, F.R.S.; Prof. F. FULLER, M.A.; J. HOPKINSON, D.Sc., M.A., F.R.S.; A. SCHUSTER, PH.D., F.R.S.; G. JOHNSTONE STONEY, M.A., F.R.S.

The following were elected Honorary Members:—

R. J. E. CLAUSIUS; H. L. FIZEAU.

After the names had been announced from the Chair, Votes of Thanks were carried:—to the PRESIDENT; to the Lords of the Committee of Council on Education; to the DEMONSTRATOR, TREASURER, SECRETARIES, and to the AUDITORS.

## THE TREASURER IN ACCOUNT WITH THE PHYSICAL SOCIETY, FROM DECEMBER 31ST, 1878, TO DECEMBER 31ST, 1879.

## PROCEEDINGS OF THE PHYSICAL SOCIETY.

15

Dr.	£ s. d.	Cr.	£ s. d.
Balance in Bank .....	55 9 6	Honararium to Prof. Everett.....	20 0 0
" paid by Treasurer .....	4 16 2	Library :—	12 0 0
Entrance-Fees .....	25 0 0	Karl's Reportorium .....	21 7 6
Subscriptions for 1878 .....	4 0 0	Williams and Norgate .....	13 7 3
" 1877 .....	10 0 0	Reports of Meetings .....	
" 1878 .....	23 0 0	Chapman :—	
" 1879 .....	131 0 0	Attendance .....	3 5 0
1880 .....	4 0 0	Petty Cash .....	1 3 6
Compositions .....	170 0 0		4 8 6
One year's Dividend on £400 4 per cent. Furness Debenture Stock, less Income Tax, 6s. 8d. ....	15 13 4	Mearns Taylor and Francis :—	
One Year's Dividend on £60 5 per cent. Midland Preference Stock, less Income Tax, 9s. 8d. ....	22 10 4	Part v. vol. ii., Proceedings .....	37 2 6
Sale of Everett's C.G.S. :—	5 3 6	Postage and addressing .....	3 10 6
Taylor and Francis .....	0 2 6	Members' extra copies .....	10 1 0
1 copy paid Treasurer .....	100 0 0	Miscellaneous Printing .....	4 7 3
Donation from R. Sabine, Esq. ....		Part i. vol. iii., Proceedings .....	42 12 6
		Postage and addressing .....	3 6 0
		Members' separate copies .....	4 10 0
		Miscellaneous printing .....	5 12 3
		Part ii. vol. iii., Proceedings .....	37 4 6
		Postage and addressing .....	3 3 6
		Members' extra copies .....	6 5 6
		Miscellaneous printing .....	4 12 0
		Wheatstone Reprint:—	
		Printing .....	137 5 6
		Packing and Postage .....	
		Advertising .....	3 2 0
		Index .....	5 0 0
		Binding .....	16 9 1
		De La Rue, Stationery .....	2 2 0
		Richardson, printing .....	2 1 6
		A. J. Clark, engraving .....	0 6 0
		Cheque Book .....	0 2 6
		Loss on Cheques .....	0 2 2
		Petty Cash :—	
		Dr. Atkinson .....	2 9 6
		Mr. Reinold .....	1 15 4
		Mr. Roberts .....	0 18 6
		Balance in Bank .....	5 3 4
		" due by Treasurer .....	136 5 2
			22 5 4
			£570 14 4

Audited and found correct,  
 FRANK CRISP,  
 GEORGE S. CLARKE, } Auditors.

London, February 14, 1880.

## PROPERTY ACCOUNT. PHYSICAL SOCIETY.

ASSETS.	£ s. d.	LIABILITIES.	£ s. d.
Subscriptions due .....	12 0 0	Subscriptions in advance .....	4 0 0
£400 4 per cent. Debenture Stock Furness Railway at 103 .....	412 0 0	Balance .....	1143 10 6
£460 5 per cent. Preference Stock Midland Railway at 123 .....	565 0 0		
Due by Treasurer .....	22 5 4		
Balance in Bank .....	136 5 2		
Stock in hand of Wheatstone's Papers and Pro- ceedings of the Society .....			
			£1147 10 6
			<u><u>£1147 10 6</u></u>

We have examined the above Account, and the Securities at the Bank, and find the same to be correct.

London, February 14th. 1880.

FRANK CRISP, }  
G. S. CLARK, } Auditors.